

Undergraduate Research Teaming Engineers with Non-Engineers

Theo Brower, Meredith Knight, Chris Rogers
Tufts University

Abstract

At Tufts University we have been experimenting with multidisciplinary teams of students to solve robotic problems. In particular, we have included a number of non-engineers in the team. Engineers are often very good at designing a solution to a problem but often fall short in the area of human interface and in communication. We have teamed them with human factors majors and child development majors in an effort to bring engineering into the non-engineering disciplines and to teach engineers how people think, how people interface with hardware and software, and how to teach. After two years, the program has worked quite well, with all team members appreciating the chance to work on a real world problem, to work with students in other disciplines, and to learn how to work effectively on a team of people with many different backgrounds.

Introduction

Seniors in most undergraduate engineering programs undertake some kind of senior capstone design project. These are usually team projects that can range from paper designs to physical prototypes. In many cases, the teams are primarily composed of engineers within the same discipline¹; mechanical engineers working with other mechanical engineers and so forth. As a result, all team members have similar expertise and experiences and do not learn much from each other. Furthermore, a homogeneous team does not reflect the composition of a team in the real world where projects require expertise in a variety of fields. A better system would create a team that emulates real world conditions², where there is only one mechanical engineer on a team of engineers from all disciplines. Or better yet, the team could consist not only of engineers but also of liberal arts majors such as seniors from the child development or education departments. This multidisciplinary team grants students exposure to new and different fields of study and gives them the opportunity to learn from and teach each other.

At Tufts University, we started this approach a few years ago with the Robotics Academy. This NSF-funded academy combines seniors in mechanical and electrical engineering, computer science, engineering psychology, and child development into teams to solve current robotic problems. The resulting teams have been very successful in developing robots as well as learning how to work in an academically diverse team. The child development major teaches the engineers how to communicate by involving them in an after-school program for local elementary school children. The engineers teach the non-engineers about engineering and the design and fabrication of the robot.

The multidisciplinary approach to teaching is not new. There have been a variety of successful multidisciplinary programs including those at Penn State University³, Carnegie Mellon University⁴, Rowan University⁵, and Purdue University⁶. The Robotics

Academy is different from the first three of these programs in that it includes non-engineering majors on the multidisciplinary teams who take an active role in the design and fabrication of the technical portions of the project. Robotics Academy participants are also take a more active role in managing the project than in those programs. The Robotics Academy differs from the EPICS program at Purdue University by having a shorter project duration (2 vs. 4 years) and a smaller, more intimate team (5-10 vs. 8-20) where there is limited vertical integration.

The creation of the Robotics Academy was motivated by the desire to help juniors and seniors develop personal and interpersonal skills, which are essential for successful professional careers. To this end, we want to answer three main questions: First, does solving a “real world problem” help motivate students learning? Second, does engaging in an interdisciplinary, student-led project allow students to develop personal and interpersonal skills more effectively than traditional coursework? Third, what are the impacts of participation in the Robotics Academy?

These research questions are answered using information gathered as part of the ongoing program evaluation of the Robotics Academy. The evaluation is composed of surveys given to students throughout their participation in the Robotics Academy as well as interviews with participants and advising professors. Thus far, the surveys have been tailored to the specific goals of the program rather than being based on standardized measures. While this prohibits comparability with other programs, this allows us to better gauge the impact of the Robotics Academy experience on the individuals involved.

The program has been in place for two years, with excellent reviews from the participants. Many cite it as the best experience they had at Tufts specifically because of the amount they learned from their team members. We have a similar program in musical instrument manufacture⁷ and are currently starting a biomedical program by bringing together engineering students and researchers nutrition. By involving the undergraduates in all parts of the research (from educational research to design, usability, and fabrication), by choosing research problems with social relevance and by letting the students be part of the selection process, we have found that the students can learn far better by “doing” and from each other than they can sitting in a classroom looking at a chalkboard.

The Program

The Robotics Academy was created three years ago in order to provide a project-based teaching and learning environment for undergraduate students. In addition, the academy would address current weaknesses in engineering curriculum⁸ and satisfy a number of requirements set by the Accreditation Board for Engineering and Technology (ABET)⁹. This research program was created to mimic the real-world design process, where not everyone on the design team is an engineer. Students’ learning is motivated by the goal of solving a real world problem. This helps to show the applicability of the research, something that is found to encourage different types of learners, especially women. In this new project-based learning environment, students of each discipline will learn to teach and mentor the others within the Academy. Finally, all students will receive

substantial mentoring from faculty members in the various disciplines as well as from a graduate student coordinator, members of the professional schools, and industry contacts. The Robotics Academy strives to include all the elements of Learning Communities^{10, 11}, and additionally allows students to develop important leadership and project management skills.

Students usually begin work on Robotics Academy projects during their junior year when they start researching a proposed project topic. The goal of the research is to help form project objectives for the following year and to get a jumpstart on the actual project work by obtaining all necessary background information. The research is done by the students with junior standing and is guided by a faculty advisor. At the end of their junior year, a preliminary project outline is formed. During the summer after their junior year, some of the students will continue working with the academy to develop robotic skills, do more focused and in depth research, and begin work on parts of the project that will be most time consuming. Over the course of the summer, the project continues to evolve due to research findings and in response to difficulties encountered during project work. A faculty advisor also guides the summer work.

During the senior year, Robotics Academy work becomes more regular and more specialized. The team(s) meet once a week to assign responsibilities and report on their progress during the previous week. These team meetings are organized and run by the Robotics Academy graduate student coordinator. The role of the graduate student coordinator is to help answer basic questions, coordinate meetings, and keep track of the material procurement and budget related tasks. The graduate student coordinator also makes sure that the team keeps on schedule to hit major deadlines, but the team members themselves handle most time management.

The final product of Robotics Academy projects has two components: a robot and a thesis. The members work collaboratively to build and program the robot, but the members are responsible for writing their own thesis. There are four major deadlines set by the Robotics Academy. The first is to have a working, proof of concept prototype at the end of the first academic semester in the middle of December. The second deadline is to have a fully functional system in late February. The third major deadline is in mid to late April when the Robotics Academy members will defend their theses. The last deadline is for the final written version of their theses, incorporating faculty feedback from the thesis defense, which must be submitted by mid-May.

To meet the above deadlines, Robotics Academy members devote a large amount of time to the project throughout their senior year. Robotics Academy seniors during the 2003-2004 school year were asked to quantify the amount of time spent working on their projects at a mid-year survey and an end of the year survey. During the fall semester, students worked between 3.5 and 23 hours per week on the project, with an average of 10 hours. The majority of the hours in the fall semester were spent designing, building and testing the robots, as well as developing the after school program curriculum. During the spring semester, students worked an average of 16 hours per week on the project, with

the range between 2.5 and 45 hours. The majority of hours during the spring were spent finalizing the projects, working on theses, and running the after school program.

While the entire team works together to develop and plan their projects, members take on an individual role, often aligned with his or her major. The mechanical engineers focus on building the robots, the electrical engineers concentrate on programming the robots, the human factors majors design “user-friendly” interfaces, and the child development majors work on creating a curriculum for an elementary or high school program. Although team members primarily work within their own fields, they each complete a variety of tasks, including some that are not directly related to their own majors. For example, non-engineers had an opportunity to work on building and programming the robot, engineers had an opportunity to help at the after school program, and all students had roles in determining deadlines, scheduling issues and procuring materials.

By contributing to a multi-disciplinary team each student gains the experience of being the “resident expert” in their particular field while learning from their teammates’ expertise in other areas. By mentoring and teaching other students, academy members gain confidence and mastery in the material themselves, as well as gaining valuable communication skills. By requiring academy members to manage their own project, they gain leadership experience that will help them succeed in any field. Finally, by including pre-service teachers, the engineers learn the importance of working with the education system, and the teachers learn the importance of teaching engineering.

Projects

The projects for the Robotics Academy are primarily chosen from the following fields: Educational Robotics, Medical Robotics, and Tele-Robotics. Faculty and students suggest potential projects by surveying current research in each field and choosing socially relevant projects. The interests and industry contacts of the Robotics Academy members and advisors are also taken into account when picking a project. Potential projects would enable academy members to work with corporations, hospitals, and/or government agencies in order to get a better idea of how the different organizations function and to directly contribute to meaningful research.

Last year, Robotics Academy members were split into two teams, each working on a different educational robotics project. The two projects were a kinetic sculpture and a team of spot finding robots. The kinetic sculpture is an electro-mechanical sculpture meant to both entertain and stimulate children. Loosely based on the famous “Rube Goldberg” device, a ball rolls down the kinetic sculpture, but to keep the ball going, the user needs to complete a number of input tasks. These input tasks were designed to help the user develop coordination and perception skills and the ball continuing on its track rewards the completion of each task. The spot finding robots were designed to work as a team to locate a spot of light and communicate back the position of this light. Additionally, these robots were used in long distance learning tasks as an innovative way to supplement science curriculum.

This year, the Robotics Academy seniors are all working on one project: The Automation of Fruit Fly Larvae Genetic Research. This project is in collaboration with genetic researchers at the New England Medical Center (NEMC) in Boston. The goal is to design a system to automate the measurement of food intake by genetically engineered fruit fly larvae in order to identify genetic influences on obesity and type II diabetes. Currently, to test the amount of food eaten by a fruit fly larva is a very slow and labor-intensive process that is currently done by hand. With the current process, it would take years to test all the genetic lines with the potential to influence obesity and type II diabetes. The challenge for the Robotics Academy team was to make a high throughput system that would enable the testing to be done in a much shorter time frame.

Robotics Academy members have worked closely with the NEMC researchers in every aspect of their design. The mechanical engineers spent this past semester working out how the robotic system will operate based on the aims of the researchers and the requirements of a data acquisition system. The engineering psychology major has met with and observed the NEMC researchers in action to determine what steps should be automated and to design a researcher-friendly user interface. The child development major has spent the semester creating a curriculum and getting it approved by the Human Subject/Institutional Review Board (IRB). Each student performed a task that suited their area of expertise, but also collaborated with the other Robotics Academy members and NEMC researchers to accomplish the project goals. In doing so they have acquired new skills and gained experiences not available in the conventional classroom.

Participants

Robotics Academy participants came from a variety of educational backgrounds. Last year, three were mechanical engineers, three were electrical engineers, two were child development majors, one was a chemical engineer, one was a human factors major and one was a computer engineer. Students found out about the Robotics Academy through a variety of methods including their advisors, professors, other students, and an email sent to all child development majors.

Participants entered the academy with varying levels of experience involving project based courses and interdisciplinary teams. Seven of the nine participants who completed the midyear survey reported that they had never worked with an interdisciplinary team before at Tufts. Two students reported that their involvement in interdisciplinary work was limited to work with other engineers. One student previously took a project based course at Tufts, two students took courses that required numerous projects but none that were completely project based, and six students had no prior experience with project-based courses. Seven of the nine participants had taken an engineering course prior participating in the project. Students' engineering coursework experience ranged from zero to more than twenty courses.

When asked about their expectations for the Robotics Academy, students' most often responded that it would be an opportunity to work closely with a group of people from diverse backgrounds. One student stated, "I expected to work closely with people in other disciplines and get to do the kinds of things that they do and thereby learn more

about other fields. I also expected to get to know more of the professors.” Other expectations students mentioned included designing and building a functional robot, gaining hands on experience, participating in a structured program, receiving guidance and clear leadership from advisors, working independently, and applying classroom knowledge to a practical problem, while using a robot in an educational setting.

Survey Results

This section is based on interviews with seniors from the 2003-2004 school year during the fall semester, surveys of the seniors both mid-year and at the end of the year, and end of year interviews with key members of the faculty and staff¹². Four professors who served as informational resources and advisors to students were interviewed; professors and staff who had limited interaction with the Robotics Academy were not interviewed. Additionally, the evaluators reviewed four theses that Robotics Academy participants wrote for additional reflections on the students’ experience. Two of these theses focused on the engineering and design aspects of the project, one focused partly on the robot design with some feedback about the Academy, and one thesis focused entirely on the logistics of the Academy itself. The charts in this section also include data from the 2002-2003 school year. The dark black line is present to remind the readers that rating scales are relative, not absolute measures.

The surveys were aimed at finding the answers to the three questions posed in the beginning of this paper. Students’ responses indicate that the opportunity to solve a “real world problem” is one of the program’s greatest strengths. One student commented, “I like the Robotics Academy because it’s not all theory, it’s practical. It’s applying what we’ve learned and using it to solve our problems.” Five out of ten participants interviewed in November of 2003 commented that the opportunity to apply previously gained knowledge to a meaningful project was the highlight of their experience. As a result of projects’ real world nature, they are more flexible and open ended than projects from other classes and students had ample opportunity to influence the direction and outcomes of the Academy. Another student remarked, “I love the creativity and the fact that you’re just allowed to go ahead and solve the problems. It’s very open.” Table II (see next page) indicates that solving a “real world problem” was reported as one of the most enjoyable aspects of the Robotics Academy and participants’ interview responses definitely indicate that it was a motivating factor.

The Robotics Academy enabled participants to develop their personal and interpersonal skills very effectively. Throughout the course of the year, participants consistently stated that the Robotics Academy made them appreciate the importance of communication and organization. Students were forced to work as a team to create deadlines and coordinate responsibilities as a result of the freedom given by Academy advisors. While working collaboratively, participants evaluated their project progress and, when necessary, set new goals. In addition, all participants felt that their knowledge of their own field of study was enhanced while in the Robotics Academy. Survey results shown in Table I (see next page) indicate that participants felt the Robotics Academy was more effective than other courses at Tufts in helping them develop the skills listed in the survey.

Even though participants reported that the Robotics Academy allowed them to develop their personal and interpersonal skills more effectively than in other courses at Tufts, it is not possible to provide objective evidence supporting this claim using only the program evaluation survey results. To fully substantiate this claim, there would have to be a more in depth study with a control group and a more standardized questionnaire. However, from the survey results, it is clear that participants felt the Robotics Academy is a very effective way of developing their skills.

When comparing the ratings between the first and second years of the Academy, students in both years gave the highest rating to their own personal skill development (in the first year knowledge of their own major, in the second year, problem and goal definition). Interestingly, students in the 2002-2003 year felt they learned more about their own major from the Academy, while students in the 2003-2004 year felt they learned more about other people’s majors. This could indicate that students in the second year worked more collaboratively across majors than in the first year.

Table I: Rate how much you feel the Robotics Academy helped you develop your skills in the following areas as compared to other courses you have taken:

Much more (1), Moderately more (2), Slightly more
(3), Equally (4), Slightly less (5) Moderately less (6),
Much Less (7)

	Average 03-04	Average 02-03
Problem/ Goal definition	1.6	2.1
Knowledge of different fields/majors	1.8	2.9
Communication skills	1.9	2.2
Ability to work in a group	1.9	2.1
Thinking from a systems perspective	1.9	*
Leadership skills	2	2.4
Knowledge of your field/ major	2.1	1.6
Organization Skills	2.5	2.7
Time management skills	2.6	1.9
Budgeting skills	2.9	2.2

**Topic not included in 2002-2003 questionnaire*

In both years of the Academy, students gave positive ratings to all of the stated goals of the Academy. Academy participants gave the highest rating to the importance of communication in group work during the 2003-2004 year. Students were motivated by the opportunity to solve a “real world” problem in both years of the project, and gained an understanding of their own field as well as developing valuable communication and group work strategies. Participants were least impressed by the mentoring they received from faculty through the Robotics Academy, as indicated by Table II. This is something we have been working to correct in 2004/2005.

Table II: Reflecting on your experiences, please indicate how much you agree or disagree with the following statements:

1=strongly agree, 2=moderately agree, 3=slightly agree, 4=neutral, 5=slightly disagree, 6=moderately disagree, 7=strongly disagree

By participating in the Robotics Academy I...	Average 03-04	Average 02-03
...gained an appreciation of the importance of communication in group work.	1.5	1.4
...enjoyed the opportunity to solve a "real world problem."	1.8	1.4
...gained a deeper understanding of my own field.	2.1	2.3
...learned strategies for communicating my ideas to people outside of my discipline.	2.2	1.9
...learned how outside organizations (such as hospitals, after school programs, parts suppliers) function.	2.5	2.9
...received mentoring from faculty that I would not otherwise have received had I not participated.	3.1	2.5

The third research question involved assessing any and all impacts the Robotics Academy had on its participants. When asked about the advantages and challenges of working with an interdisciplinary team, students responded that exposure to a variety of perspectives and learning styles, having other team members to introduce them to different fields, becoming aware of resources and developing communication skills were advantageous aspects of working with people from different majors. Students reported that finding a way to communicate ideas and thoughts and schedule meeting times that worked for everyone were the greatest challenges. They reported that other challenges were "keeping everyone on the same page," coordinating the timing of tasks and responsibilities and integrating everyone's ideas and visions into the goals of the Robotics Academy.

When asked how the Robotics Academy was different from other courses at Tufts, nine out of ten participants commented that the Robotics Academy gives students more freedom because faculty act as advisors rather than professors. Students recognized the added responsibility of the project, commenting that "This is a bigger pressure project because we have so much freedom" and "It's an interdisciplinary experience, [our advisors] give structure but it's up to us to keep the pace going, to make sure that everyone is doing their own thing and to keep collaborating each week. You're never really taught to do this so it's more of a challenge than you'd think." Students also noted that the Academy is smaller, less structured, depends upon interdisciplinary collaboration, and requires significantly more hands on work than traditional courses.

*Table III : How would you rate your experience in the Robotics Academy?
Excellent (1), Very good (2), Good (3) Fair (4) Poor (5)*

	Average 03-04	Average 02-03
Fall Semester	1.7	1.4
Spring Semester	2	1.8

In both years of the academy, students gave the Robotics Academy high ratings, though the rating is slightly lower in the second semesters of the project than the first semesters. This phenomenon is probably due to the increased workload in the second semester when the project is due and the thesis must be written. Despite this, when asked if they would recommend the Academy to other students, four students said that they would “probably” recommend the Robotics Academy to another student and six students said they “definitely” would recommend it.

Program Difficulties

While the Robotics Academy members were very happy with their experience in the program, they also cited a number of things that could be improved. One issue is the role and involvement of faculty in the Robotics Academy. The majority of suggestions for improvement revolved around the capacity in which professors and advisors participated in the program. Students appreciated the graduate student coordinator and felt that he was necessary but also felt that they could have more support from actual faculty members as well. Four of the ten participants suggested that the Academy would be improved if they could “get the professors more involved.” Many reported that their frustrations with professorial involvement stemmed from the fact that professors’ roles were never clearly communicated to participants. Therefore, they did not know what to expect or how to interact with professors. Student comments regarding this subject included: “I felt that the expectations of professors were not clearly communicated to students. The Academy seemed to have no plan for how it would progress throughout the year and it resulted in the students feeling rushed about deadlines and often confused. More input from advisors might have helped this,” “More clarity in expectations for the project and grading would have been helpful” and “We need more resources available, perhaps more professors.” Other suggestions regarding professors’ roles included regularly scheduled meetings with professors to “discuss problems” and “assist more with the planning and the execution of the project”. One student suggested that the graduate student could play a more active role in involving the faculty in the Academy, through seminars or class type presentations.

Another point of difficulty was in developing a “common knowledge base” for Academy participants. While one of the highlights of the Academy was the opportunity to work with an interdisciplinary team, participants often struggled because there was such variation in skills, knowledge and background. Participants felt that improvement could be made if the roles and expectation of students from each background had been specified. A student suggested that there be an “introduction to the expected work that other majors would be doing over the course of the year so that there could be improved communication between group members.” Faculty advisors and the staff member echoed this concern in their interviews, suggesting that an interdisciplinary course or seminar during which faculty could present ideas and relevant research. Such a course could help establish a common knowledge base that the Academy participants could share. One

student wrote, “When I started I knew absolutely nothing about robotics and it would have been helpful to have at least a little background knowledge... It would have been helpful if we had been encouraged to look into and read relevant papers. Perhaps this could be done through a class.”

Other areas for improvement include establishing a dedicated lab space for the Robotics Academy where projects can be stored, fabricated, and worked on whenever students want to. Besides a place to work, students also found it difficult to make a weekly meeting time that everyone’s schedule could accommodate. To fix this it has been suggested that the Robotics Academy should be turned into a class so that it has a designated meeting time that would not conflict with other classes. Finally, they suggested a more structured recruiting process for future academy members because it is difficult to advertise to students outside of the mechanical engineering department.

Conclusion

Judging by student and faculty responses, the general model of the Robotics Academy has been very successful. The program provides powerful learning experiences not available through current educational methods. Through projects that address current, socially relevant, research problems, Robotics Academy members are given the opportunity to apply their expertise as a part of an interdisciplinary team. Next year’s team has decided to tackle the problem of how to bring robotics to blind people. Interactions between team members, researchers, and advisors allow students to acquire real-world project skills along with teaching and leadership experience. Further, by involving engineering and non-engineering undergraduates on the same project, each person learns the importance and comes to appreciate the unique contributions made by team members from other disciplines.

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Biographical Information

THEO BROWER is a graduate student in Mechanical Engineering at Tufts University and is currently the Robotics Academy graduate student coordinator. He received his BS in Electrical Engineering from Princeton University.

MEREDITH KNIGHT is a research associate at the Center for Engineering Educational Outreach (CEEO) at Tufts University. She is the program manager for the Pre-College Engineering for Teachers (PCET) Program and the 4 Schools for Women in Engineering Program.

CHRIS ROGERS is a professor of mechanical engineering at Tufts University. His research is in particle-laden turbulence, chemical-mechanical planarization, musical instrument engineering, and robotics. He also has been working for the past 15 years with elementary school teachers to teach math and science through engineering.