Multidisciplinary Microrobotics Teaching Activities in Engineering Education

Ferat Sahin, Ph.D., and Wayne Walter, Ph.D., P.E.
Kate Gleason College of Engineering
Rochester Institute of Technology
79 Lomb Memorial Drive
Rochester, NY 14623
feseee@rit.edu, wwweme@rit.edu

1 Introduction

Within the College of Engineering at RIT, a small nucleus of faculty from four different departments have been quietly developing expertise in the area of MEMS and Microrobotics by working on multidisciplinary projects of mutual interest at various levels. This paper discusses our experience in teaching microrobotics by designing multidisciplinary projects for undergraduates and their integration with research and graduate students. It also discusses the broader impact of these activities on various levels of students. The activities can be categorized in three levels: undergraduate teaching, graduate research, and clubs and organizations.

This paper explores our experience in developing these projects and related research, including our lessons learned so far, and our plans for the future. Some statistical data are also provided to show the broader impact of these multidisciplinary microrobotics teaching and research activities on the students.

The paper starts with a discussion on learning styles and how teamwork and multidisciplinary projects tie to theses learning styles. Then, multidisciplinary microrobotics projects are explored including their organizational structure and their ties to the existing research. In section 4 the effect of multidisciplinary microrobotics projects on research and teaching integration is discussed. Clubs and student organizations are presented in Section 5, specifically Multidisciplinary Robotics Club. Section 6 presents the broader impact of these projects in terms of curriculum development, student population, and retention. Finally, the paper is summarized and conclusion obtained from these projects and educational experiences in Section 7.

2 Learning Styles and Teamwork (Multidisciplinary Projects)

People can be categorized as having five distinct learning traits according to the Felder-Silverman Learning Style Model [1]. Felder presents these traits as perception, input modality, organization, processing, and understanding [2]. According to the model, each of these traits has two possible types.

Sensory learner and ***intuitive learner*** are learning types in terms of how students perceive information. Sensory learners favor information through their senses; sights, sounds, and physical sensations. On the other hand, intuitive learners favor information that arises internally through memory, reflection and imagination [3]. The strength of an individual's preference for sensation or intuition can be with the Myers-Briggs Type Indicator [4, 5]. Modality of the sensory information creates ***visual learners*** and ***verbal learners***. Visual learner gets more information from visual information such as pictures, diagrams, and schematics. Verbal material such as written and spoken words and mathematical formulas provides more information for a verbal learner [6, 7].

How students organize information changes on whether there are ***inductive learner*** or ***deductive learners***. Inductive learners prefer to learn the material by seeing specific cases first such as observations, experimental results, and numerical examples. Then, they work up to underlying principles and theories by inference. Deductive learners start with general principles and theories and deduce consequences and application [2]. Research shows that induction generates deeper and longer retention of information and provides students higher confidence in their problem-solving skills [8, 9]. Students process information *actively* or *reflectively*. ***Active learners*** tend to learn when they actually do something active such as trying things out and bouncing ideas off others. ***Reflective learners*** prefer to do their processing introspectively and thinking things through before trying them out [10].

Students progress towards understanding *sequentially* and *globally*. Small-connected parts facilitate absorbing and acquiring understanding of the material for ***sequential learners***. Sequential learners can solve problems in pieces with a possible lack of understanding the big picture. ***Global learners*** absorb information in seemingly unconnected parts and reach understanding in large holistic leaps [2]. Global learners are slow to understand the pieces of the problem but once they grasp the big picture they can see connections to other subjects that sequential learners cannot see [11].

The multidisciplinary microrobotics projects can provide great learning experience for the students since it can cover most of the traits in the learning styles. It can also be the place for most types of learners such as sensory learners, visual learners, inductive learners, active learners, sequential learners and global learners. Sensory learners benefit from the multidisciplinary microrobotics projects because projects are hands on and very suitable for physical sensation. Visual learners enjoy these projects also because all the projects have many visual aspects such as schematics, motion, and diagrams. Additionally, inductive learners benefit the most from the microrobotics projects because the projects consists tremendous amount of experimental work and numerical problems and solutions. Finally, the microrobotics projects present higher benefit for both sequential and global learners since the projects focuses on the big picture as well as the pieces of the big picture. There is an opportunity for detailed exploration and global exploration during the projects. The next section explores the multidisciplinary microrobotics projects carried out in the College of Engineering at Rochester Institute of Technology.

3 Microrobotics Projects

3.1 Organizational Structure

The microrobotics projects are carried out by employing students from several levels. The organizational structure consists of graduate students, senior design team, co-op students, and volunteers from student clubs. Graduate students play a leader role in the team so that the team succeeds in its goal. They also play an important role in research and teaching integration by interacting with undergraduates. They learn leadership and project management skills through these projects. A senior design team, lead by the graduate students, carries out the projects. The senior design teams are multidisciplinary consisting students from at least two departments.

Rochester Institute of Technology has a mandatory co-op for juniors and seniors in order to prepare them to the industry. The microrobotics projects often get great help from co-op students since they work 40 hours a week for two quarters (20 weeks). They earn co-op credits as well as learn and practice in their majors by working on these projects. Final component of the microrobotics projects is student-run clubs related to robotics and engineering. Students from these clubs provide voluntary help to these projects and create visibility for the projects and RIT by competing in the regional and national design competitions. Figure 1 shows the organizational structure of a typical microrobotics projects. Next sections explore some of the multidisciplinary microrobotics projects performed at RIT.

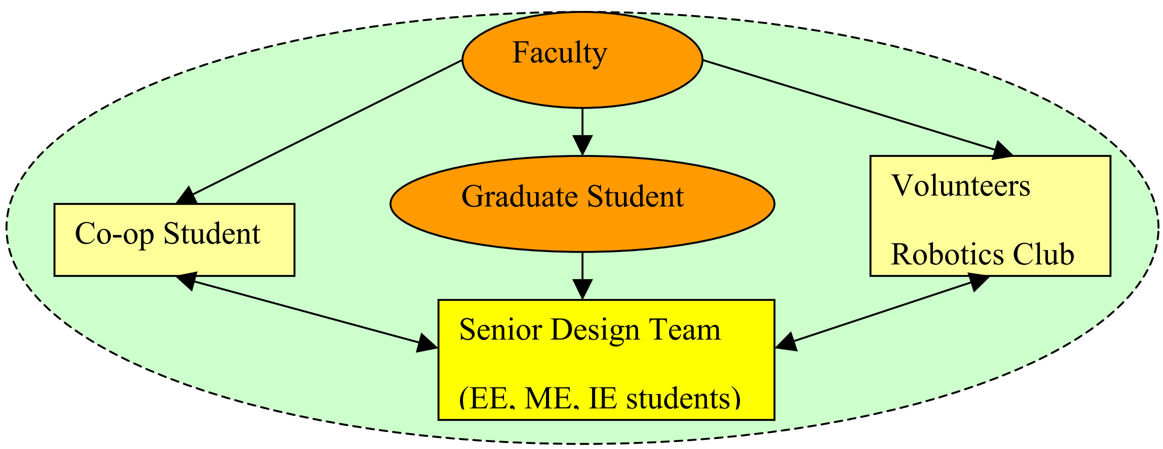


Figure 1. Organizational structure of a typical multidisciplinary microrobotics project.

3.2 MEMScouts

The use of swarms of small, inexpensive, autonomous, cooperative agents is an increasingly attractive engineering solution to a wide variety of real world problems. Swarms of agents offer the possibility of "covering more ground more cheaply and more quickly" when the task at hand is a non-localized problem, such as reconnaissance, search and rescue, or wildfire detection.

At the undergraduate level, multidisciplinary Senior Design projects have been recently undertaken on various aspects of microrobotics. The Laboratory for Autonomous, Cooperative Microsystems (LACOMS) at RIT is developing a prototype concept called MEMScouts in order to demonstrate an effective system for deploying swarms of micro-agents to remote locations under real world conditions and to cover several areas of microrobotics teaching and research. MEMScouts concept is presented in Figure 2.

The MEMScouts system has three major components:

1. A Tactical Control Center (TCC) provides the human interface for monitoring and guiding the action of the swarm from a safe location.

2. The *Mothership* is a miniature vehicle that ferries the swarm to the remote general location of the mission. After deploying the swarm the *Mothership* may loiter in the area and act as a local communication and control center in support of the swarm's actions.

3. MEMScouts is a collection of micro-agents that act cooperatively to accomplish the given mission. The agents come in a wide variety of configurations and possess a range of capabilities. Non-mobile agents are known as *SENscouts* and remain fixed at the point of deployment. SENscouts typically consist of a sophisticated MEMS-based sensor package that collects local environmental data and uploads these to the Mothership for relay to the TCC. However, SENscouts may also have the ability to take some form of action such as RF signal jamming or the dispersal of chemical agents. GROUNDscout*s* are land-mobile agents that can navigate over terrain to pursue the goals of the mission. They can be endowed with the same set of capabilities as the SENscouts, but they also offer the ability to act on the environment with force by, for example, moving objects, digging, or cutting. *AIRscouts* are mobile airborne micro-agents and *AQUAscouts* are mobile waterborne micro-agents that possess capabilities similar to GROUNDscouts.

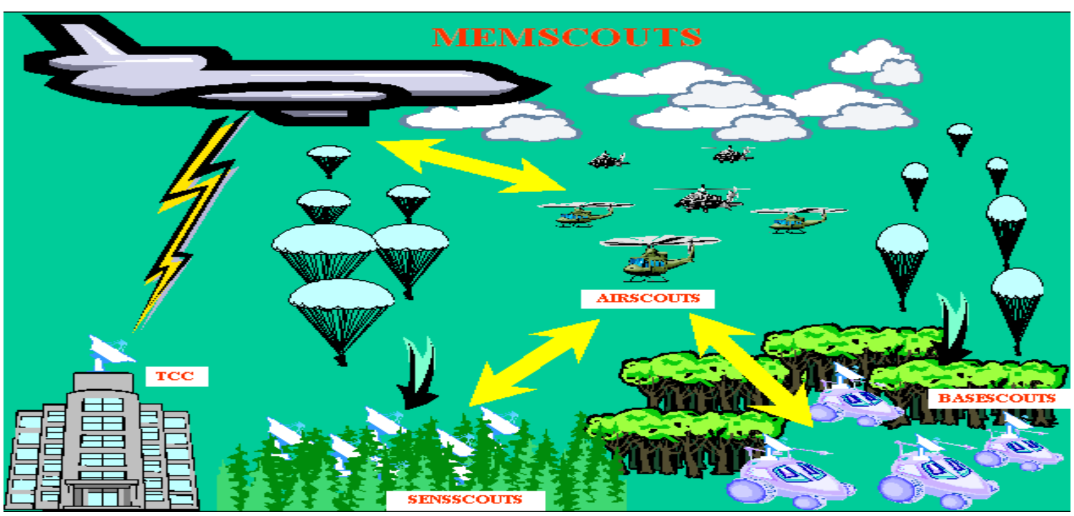
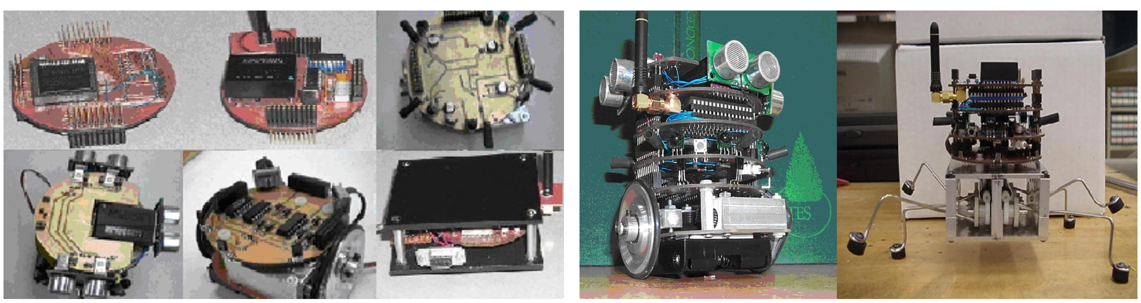


Figure 2. MEMScouts Scenario – Cooperative heterogeneous mobile microrobots.

3.2.1 GROUNDscouts

GROUNDscouts are mobile ground vehicles that gather information and accomplish a certain task obtained from a command center in LACOMS' family of scouts (robots). Since the problem domain may vary from application to application, the modular architectural approach is followed in designing GROUNDscouts. For example, the robot needed for a wild fire application will be very different than the robot needed to monitor the chemical leakage in a nuclear reactor. Especially, their sensory and locomotion abilities should be different for these applications. Along with the hardware modularity, the robots need a collective intelligence to solve a given problem in the environment. Some swarm intelligence algorithms, ant behavior [12], particle swarm optimization [13], and decision-theoretic intelligent agent [14, 15], have been developed. The decision-theoretic intelligent agent approach has been successfully tested on two of the GROUNDscouts.

The robot is modular in architecture in that locomotion, communications, control, and sensors are each on a separate layer. Each layer (module) is independent from each other but have the same pin connections. They can be plugged together in any order. There are 7 levels/stages in the robot: base, motor drivers, power, controller, communication, and sensors. Base level includes the mechanical design of the wheels/legs, suspensions, and motors. Motor drivers level handles the driving motors. Power level has a battery, a regulator and a recharging circuitry. Controller level consists of the microcontroller (8051) and memory. Communication level consists of a 933 MHz transceiver and a PIC controller to handle the communication protocol. Finally, sensors level is responsible for collecting information about the environment using its ultrasound, infrared, and proximity sensors. The full size of the robot is 8 cm in diameter and 10 cm in height. Figure 3 (a) shows all the levels and auxiliary parts for the robots.



(a) (b)

Figure 3. Control, Communication, Sensors, and Locomotion Modules

In addition to communication module in the robots, we have developed a communication module for the host computer, right bottom corner image in Figure 3 (a). The host computer receives data from the scouts and sends common tasks.

As stated earlier, the most important part of the modularity is the ability to swap the bases while keeping the rest of the robot the same. In addition to the wheel-based locomotion, a leg-based locomotion unit is designed for the robot. This fits very well into the modular architecture concept because the wheel-based locomotion unit and the leg-based locomotion unit are the sub-modules for the locomotion module of the robot. Figure 3 (b) shows two robots with different locomotion and sensor capabilities. Wheel-based robot has ultrasonic, infrared and proximity sensors whereas the leg-based robot has only infrared and proximity sensors. By combining different sub-modules, application specific robots can be constructed without changing the software and adding extra hardware to the system.

Figure 3 (b) shows the wheeled locomotion module replaced with a legged module more appropriate for uneven terrain [16]. Both robots are controlled by an 8051 microcontroller, and are not tethered. Wireless communication is provided by RF transceivers. Locomotion is either by servomotor driven wheels in response to sensor input, or servomotor driven legs through a gear train. The modularity exhibited by this robot could be easily adapted for the development of a new mobile sensor platform useable for structural health monitoring and repair, and many other applications. The prototypes introduced in this section are currently being redesigned for manufacturing of modular extensible mobile microrobots to be used in various application domains such structural health monitoring and wild fires detection and control.

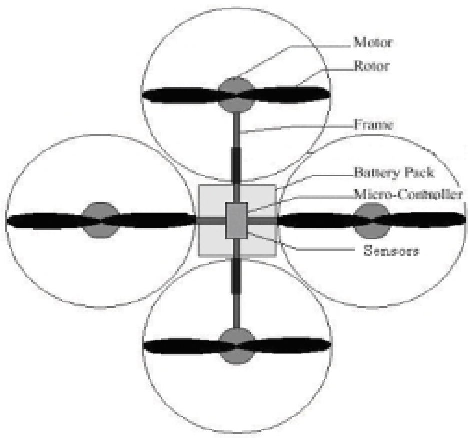
3.2.2 SENscouts

The SENscouts project involved non-mobile agents fixed at the point of deployment. The objective of the SENscouts project was to develop a sensor package of minimal size that could be dropped on the ground from the Mothership, survive the fall, and be operational. A senior design project involved the development of the exterior structural and internal electronic requirements to allow a set of SENscouts to reach their target and transmit signals that can be received by the Mothership. The devices had to fit into the payload bay of the Mothership (a RC model airplane) that was available at RIT, and had to be able to simultaneously transmit light intensity and temperature readings. Each SENscout device had to be operational after being dropped them from the tallest dormitory building accessible on campus (10 stories). The devices had to have a maximum omni-directional transmission range of 100 m, a temperature range from minus 20C to +125C, a sampling rate of 1 minute per measurement, and be environmentally friendly.

After identifying numerous candidates for the mechanical architecture, an ellipsoidal-shaped “pod” was chosen by the ME team for the final packaging design. The pod was encapsulated in an EAR™ damping material to help absorb some of the impact with the ground. The size of the pod was determined by the electronics system that it needed to contain. This was designed and built by a team consisting of four EE students. SENscouts needed to communicate with the Mothership, and as a result, the size of the electronics module was driven in reality by the size of the smallest wireless transceiver boards that could be found. The size of the resulting pod was approximately two inches.

3.2.3 AIRscouts

AIRscouts are designed by a multidisciplinary senior design team. The team consisted students from Electrical, Mechanical, and Industrial Engineering departments. The team named the aircraft as QuadCopter because of its unique architecture. The device is a miniature mobile sensor platform reminiscent of a modern day helicopter. It is roughly 6-8 inches in diameter. It is powered by four fixed-pitch rotors; two that spin clockwise and two that spin counterclockwise. When all four rotors spin at the same rate, the moments will cancel and equilibrium can be achieved. Changing the speed of the rotors in special patterns can produce elemental operations of helicopter flight of which all flight maneuvers can be broken down into: pitch, roll, yaw, collective, and slide. The device contains a central processing "brain" which interfaces with flight sensors, reconnaissance sensors, navigation system, and rotor drives [17]. Physical architecture and complete version of the aircraft is shown in Figure 4.



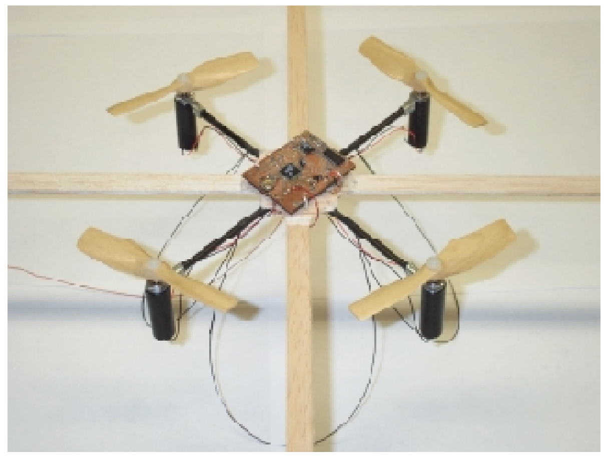


Figure 4. Physical architecture and complete QuadCopter.

3.2.4 AQUAscouts

AQUAscouts are small unmanned MEMS-based underwater mobile robots that autonomously operate below the surface of water to gather data, wirelessly transmit that data, and display the data in real-time on a web server at a central command center. In an initial AQUAscouts project, a small-untethered autonomous submersible robot called Aquato was built to collect temperature and pressure data as a function of depth [18]. A BASIC Stamp SX2 microcontroller was used to control a thruster, and record data from a thermistor and pressure transducer. Data was stored in the microcontroller EEPROM, uploaded to a laptop when the robot surfaced, and later displayed on the web. Thermoclines, abrupt changes in water temperature, were investigated when the robot was successfully tested in Canandaigua Lake, one of the Finger Lakes of New York State.

Figure 5. AQUATO, a Submersible Autonomous Robot for Underwater Data Gathering

Table 1. : Robot Specifications

Parameter	Value
Weight	32 lb.
Overall Height	49 in
Overall Width	21 5/8 in.
Diving range	33 ft
Cost	$200

A second version of AQUAscouts was recently built in the undergraduate ME robotics course [19]. Called the "Underwater Mine," this device was an autonomous underwater robot capable of hovering at a preset depth. By comparing a pressure sensor reading with a preset value, two motor-driven propellers were controlled by a STAMP microcontroller. It also had a bump ring that caused the mine to surface and turn on LEDs that simulated an explosion, if a ship touched the ring. An additional Senior Design project now in progress, called the Lake Drifter, will take temperature and turbidity readings vs. depth in Lake Ontario. Plans have been made to build an autonomous submersible robot capable of diving beneath the lake surface to do this.

3.2.5 Mothership

The Mothership is essentially an RC model airplane, but was heavily modified to incorporate an internal bomb bay module, a GPS guidance system, a STAMP-based microcontroller, a video camera, and RF communications equipment. The craft takes off and lands under hand control. While in the air, the craft is controlled either from a RC handheld controller, or via instructions relayed to the craft from a laptop computer. Altitude information is provided to the STAMP through a Garmin ETREX Summit hand-held GPS unit. The STAMP interprets this information and adjusts the elevator angle to maintain a pre-set altitude. The craft is manually flown into a designated drop zone. At the appropriate time, the GPS notifies the STAMP that a SENscout should be released. The bomb bay module receives instruction from the STAMP and releases the SENscout. The bomb bay holds a minimum of 4 SENscouts, and is able to individually release each one. This project initially strived to include a downward facing video in the craft that would relay video back to the laptop. The video would essentially enable blind flight of the craft from the laptop. Though we hoped to be able to fly the plane from the laptop using video feed, this secondary objective was not implemented.

3.3 WaferBot

The WaferBot project provides the opportunity to pursue research on MEMS-based microrobots. The possible applications are covert data gathering, medical health monitoring, structural health monitoring, and search and rescue. WaferBot is a 5 x 15 mm legged wafer that walks. Legs are fabricated in silicon with polyimide filled heated trenches. After curing with temperature, the polyimide shrinks causing the leg, after release, to curl up. Figure 6 illustrates the curing process and the shape of the leg before and after curing. Heating causes the leg to straighten, producing the walking action. Initial work has focused on thermal simulation and optimization and on fabrication studies to understand the fabrication building blocks necessary to build a complete leg.

A computer-simulated model for transient heat and deflection analysis was validated for the serpentine heater case in the high frequency domain. Some differences between the simulated and experimental results reported by T. Eberfors were noted in the low frequency domain [20]. A need for an active cooling mechanism was identified as convection plays a small role in the heat transfer process. It was also observed that all the V grooves do not contribute equally to the actuation process. Thus, the heater location and the power supplied to each V groove needs to be optimized, so that all V-grooves participate equally in the actuation process. The role of various parameters (thermal conductivity and wall temperature) has been investigated. A number of issues have been identified which require future work:

1) Temperature dependent material properties.
2) Coupled electrical-thermal effects.
3) Wall temperature effects employing an exponential function.
4) Optimal heater location.
5) Residual stress effects.
6) Development of an active cooling mechanism.
7) Fabrication and test of a leg actuator prototype (currently in progress at RIT).

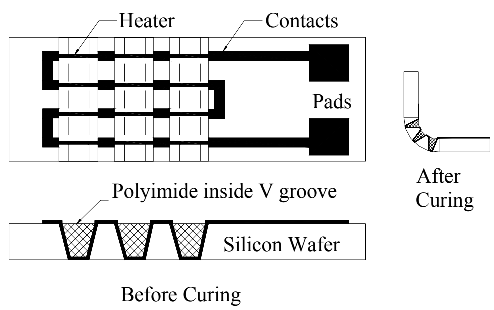


Figure 6. Schematic of Serpentine heater.

Fabrication activities to date have focused on developing the various building blocks needed to fabricate the leg actuator prototype including: polyimide thickness vs. spin speed, shrinkage coefficient for polyimide vs. curing temperature, plasma etch and STS etch capabilities.

4 Research and Teaching Integration

The multidisciplinary design teams work closely with masters level graduate students since these projects are driven by the research conducted mostly under the Laboratory for Autonomous Cooperative Microsystems (LACOMS). Several graduate students and faculty have been conducting research mainly in swarm intelligence, micro locomotion, MEMS based microrobot, distributed sensors, and intelligent agents. This research requires robotic platforms to conduct tests and experiments to verify the algorithms and systems developed. This creates two opportunities in terms of students. First, undergraduate students can get a chance to do research. Second, the graduate students gain leadership and project management experience by directing and administering these projects. Additionally, these projects prepare graduate students for the newly announced PhD program in Microsystems Engineering at RIT.

5 Student Clubs and Organizations

Another activity the multidisciplinary microrobotics projects bring to our college is clubs and organizations driven by students who are involved with above projects. Multidisciplinary Robotics Club (MDRC) is an example of such organizations. A Multi Disciplinary Robotics Club ***(MDRC) is established*** in Spring 2002 to create a home for the students [21]. The MDRC consists of students whose backgrounds are from all the departments in the college. There are currently four faculty advisors for the club from EE, ME, and CE departments. Presently, the MDRC has approximately 50 members (four faculty members). The main goal of the robotics club is to compete at the regional and national robotics competitions such as ***RoboCup*** [22] and ***BattleBot*** [23]. The club works together with a multi disciplinary design team to design soccer playing robots and compete in the next RoboCup competition. The MDRC is helpful to reach out underrepresented students.

6 Broader Impact

This section presents the broader impact of multidisciplinary microrobotics projects in terms of curriculum development, student population, and retention.

6.1 Curriculum Developments

Student teams working on these microrobotics projects, with members from various departments, were co-advised by faculty from at least two departments. The departments involved with multidisciplinary microrobotics projects are from Electrical, Mechanical, Industrial Engineering departments. As a result of these projects, plans are currently underway to develop an electro-mechanical concentration within the college, with funds to be hopefully provided in part by NSF-CCLI funding. Courses within this option include Mechatronics, Principles of Robotics, Micro and Mini Electromechanical Motion Devices, and a multidisciplinary Senior Design project.

6.2 Student Population

There are two major projects: MEMScouts and WaferBot. The MEMScouts family consists of five members: GROUNDscouts, AIRscouts, SENscouts, AQUAscouts, and the Mothership. The multidisciplinary microrobotics projects are also supported by students from the

Multidisciplinary Robotics Club as explained in Section 5. The composition of the multidisciplinary teams and the MDRC is shown in Table 2.

Table 2. The composition of the multidisciplinary teams and projects

Project		Multidisciplinary Design Teams	Co-op	Independent Study	Graduate Student	Faculty
MEMScouts	GROUNDscouts	Version 1: 4 EE, 2 ME students		1 ME student, 2 EE students		1 EE, 1 ME
MEMScouts	GROUNDscouts	Version 2: 3 EE, 1 ME students				2 EE, 1 ME
MEMScouts	GROUNDscouts	Final Version	1 EE, 1 ME		2 EE students	1 EE, 1 ME
MEMScouts	AIRscouts	3 EE, 3 ME, and 1 IE students				1 EE, 1 ME, 1 IE
MEMScouts	SENscouts	4 EE, 2ME, 1 IE students				2 EE, 2 ME, 1 IE
MEMScouts	AQUAscouts	3 ME, 1 IE, 1 EE students		1CE, 2 ME students	1 IT student	2EE, 1ME
MEMScouts	Mothership	3ME, 1EE				1 EE, 2 ME
WaferBot			1		1 ME, 2 EE	2 ME, 1 EE,
MDRC		1 EE, 2 ME		20 EE, 15 ME, 5 CE, 5CS	4 EE	2 EE, 1 ME, 1 CE

6.3 Retention

The multidisciplinary robotics projects and the MDRC attract many groups of students since they are interdisciplinary experiences available for ME, EE, MicroE, CE, IE, and CS students. Since the students are involved in various activities, they better connect with their major, gain team experience, and understand other major's language. The sense of accomplishment they gain during the projects and design competitions helps address the retention problem. The popularity of the projects and activities also attract women and minority students, as well as bright learning disabled and hearing-impaired students.

Multidisciplinary activities create a sense of community in the College of Engineering. Students who are involved in these activities understand their role in the College of Engineering and their studies. The sense of community and their connection with their major help them stay in the College of Engineering. This helps improve the retention problem concerning freshman and sophomore as well as juniors in the college. All of the students involved in these projects have continued their studies in the college.

7 Summary and Conclusion

The multidisciplinary projects and MDRC activities have been well received by students with noticeable enthusiasm, and have appreciably improved the sense of community among the participating students. Interaction and communication between the disciplines involved has increased. Students are gaining a better understanding of the engineering field overall, and a better appreciation and respect for other disciplines. Students are learning from each other, and this in itself, is a great benefit. Projects are state-of-the-art, and improving in technical sophistication with each evolution. Collaboration between faculty has increased and this fits well with the mission of the college to focus on multidisciplinary interaction at all levels. At this time, we are pleased with the results we have been able to achieve, and we anticipate further successes as we further develop our program.

8 References

[1] R. M. Felder, "Matters of style," *ASEE Prism*, pp. 18-23, 1996.

[2] R. M. Felder, "Reaching the second tier – Learning and teaching styles in College Education", *Journal of College Science Teaching*, vol. 23 (5), pp. 286 – 290, 1993.

[3] R. M. Felder, "Meet your students: 1. Stan and Nathan", *Chemical Engineering Education*, Spring: 10.

[4] G. Lawrence, *People Types and Tiger Stripes: A Practical Guide to Learning Styles*, 2nd Edition, Gainesville, FL: Center for Aplications of Psychological Type, 1982.

[5] I.B. Myers and M.H. McCaulley, *Manual: A Guide to the Development and Use of the Myers-Briggs Type Indicator*, 2nd Edition, Palo Alto: Consulting Psychologists Press, 1986.

[6] R. Bandler and J. Grinder, *Frogs into Princes*, Moab, UT: Real People Press, 1979.

[7] W.B. Barbe and M.N. Milone, "What we know about modality strengths", *Educational Leadership*, vol. February, pp. 378 – 380, 1981.

[8] R. M. Felder, "How students learn: Adapting teaching styles to learning styles", *Proceedings of the ASEE/IEEE conference on Frontiers in Education*, pp. 489, CA, 1988.

[9] W. MacKechie, "Improving lectures by understanding students' information processing", In McKeachie, W. J., Ed., *Learning, Cognition, and College Teaching*. New Directions for Teaching and Learning No. 2, San Francisco: Jossey-Bass, p. 32, 1980.

[10] D. Kolb, *Experiential Learning: Experience as the Source of Learning and Development*, Englewood Cliffs, NJ: Prentice Hall, 1984.

[11] R. M. Felder, "Meet your students: 2. Susan and Glenda", *Chemical Engineering Education*, Winter: 7.

[12] Kumar V. and Sahin F, "A Swarm Intelligence Approach for the Mine Detection Problem," in *Proceedings of the IEEE SMC2002 Conference*, vol. 3, Tunisia, October 2002.

[13] Tillet J., Rao R., Sahin F. and Rao T.M., "Cluster-head Identification in Ad Hoc Sensor Networks Using Particle Swarm Optimization", to appear in *the proceedings of the 2002 IEEE International Conference on Personal Wireless Communication*, 2002.

[14] Tillet J. and Sahin F, "IntelliAgent: Simulation Environment for Cooperating Intelligent Agents," *Proceedings of the IEEE SMC2002 Conference*, vol. 3, Tunisia, October 2002, Tunisia, October 2002.

[15] Sathyanath S and Sahin F, "*AISIMAM* - An AIS based Intelligent Multi Agent Model and Its Application to Mine Detection Problem," in *Proceedings of the IEEE SMC2002 Conference*, vol. 3, Tunisia, October 2002, Tunisia, October 2002.

[16] Michael Lent, Alan Kudla, Michael Bodnar, Kim Pearsall, "Legged Robot," Final Report for Multidisciplinary Design, May 2002.

[17] Justin Bickford, Stefan Preble, Chris Przybyla, Ross Clary, Aaron Pierce, Kevin Kyte, "QuadCopter", Final Report on Multidisciplinary Senior Design Project, May 2002.

[18] Rick Stone, Wayne Walter, "AQUATO, a Submersible Autonomous Robot for Underwater Data Gathering," Proceedings of the Fifteenth International Conference on Systems Engineering - ICSEng 2002, Las Vegas, 6-8 August, 2002.

[19] Matthew Vicker, Daniel Willistein, "Depth Regulating Mine," Final Report for Robotics, November 2002.

[20] Ritesh Khire, Satish Kandlikar, and Wayne Walter, "Computer Simulated Transient Analysis of a Polyimide V-Groove Leg Actuator with Serpentine Heater for a Walking Micro-Robot," First World Congress on Biomimetics and Artifical Muscles, Albuquerque, New Mexico, December 9-11, 2002.

[21] "Multi Disciplinary Robotics Club (MDRC) at RIT",http://www.geocities.com/mdrc_rit/.

[22] RoboCup Official Website, http://www.robocup.org/.

[23] Official BattleBot Website, http://www.battlebots.com/.