The Mechatronics Road Show: Building on Success in Mechatronics Curriculum Development

Sandra A. Yost, Daniel D. Maggio
Dept. of Electrical and Computer Engineering/
College of Engineering and Science
University of Detroit Mercy, Detroit, Michigan

Abstract:
This paper describes a progression of successful pre-college programs that have grown from a comprehensive mechatronics curriculum development project sponsored by the National Science Foundation's Course, Curriculum and Laboratory Improvement (CCLI) Program[1]. The students served by these programs are predominantly female and from underrepresented minority groups. The focused hands-on modules in these programs have introduced many students to a number of activities, including wiring electronic circuits, programming microcontrollers, and fabrication of parts using a rapid prototyping system.

The most recently implemented program allows mechatronics design activities to take place in the secondary school setting, allowing a larger number of students to participate than programs that require students to come to the university campus. In this paper, we describe how this program evolved from a number of other successful pre-college programs in mechatronics, made possible in part by the NSF grant. In particular, this program is modeled on a highly successful residential summer camp for high school girls.

Mechatronics Curriculum Development

In 1999, the University of Detroit Mercy (UDM) was awarded an NSF-CCLI grant for comprehensive curriculum development in mechatronics[1,2]. The project included the development of a new upper-division undergraduate course that incorporates team-oriented, project-based learning[3]. The incorporation of mechatronics in some existing courses was also a goal of the project[4,5]. Finally, the development of a pre-college outreach component was intended to address future engineering workforce considerations[6]. The project specifically targeted women and underrepresented minorities, especially in regards to the pre-college component. A follow-up CCLI grant awarded in 2003 supports the development of hands-on modules in sensors and actuators for the pre-college populations served by the previous project [7].

Detroit Area Pre-College Engineering Program

The Detroit Area Pre-College Engineering Program (DAPCEP) is a non-profit, Detroit-based organization whose mission is to increase the number of under-represented minority students prepared to enter the fields of engineering and science. One way DAPCEP accomplishes its mission is by funding Saturday classes at local institutions. The University of Detroit Mercy's Saturday programs are offered on six consecutive weekends in the fall and spring. Approximately 2,000 students (mostly from the City of Detroit) in the 4th through 12th grades

take courses in math, science, computers and engineering at UDM during the 2003-04 academic year. UDM's College of Engineering and Science has been servicing the DAPCEP organization for nearly twenty-five years and is the leading institution in the number of students enrolled (approximately 40% of DAPCEP students attend courses at the UDM site). In addition to DAPCEP's Saturday programs, the College offers more intensive summer daily programs (Monday through Friday, with a residential component). Our UNITE program has been in existence for twenty-two years. Annually, over 98% of the DAPCEP students who participate in programs at the University of Detroit Mercy are African-American.

In 1998, two of the PI's of the mechatronics grant (Dr. Mohan Krishnan and Dr. Sandra Yost, both from the Electrical and Computer Engineering Department) were asked by Dan Maggio, Director of Pre-College Programs in the College of Engineering and Science, to teach a DAPCEP course in principles of electrical engineering. Krishnan and Yost, along with Dr. Shuvra Das, their co-PI from Mechanical Engineering, proposed a new course in mechatronics. The first offering (Spring 1999) of this 18-hour course introduced students in grades 10-12 to microcontrollers and their use with sensors and actuators to accomplish some simple tasks. The course took place in a context of hands-on, team-oriented activities during six three-hour sessions. The Basic Stamp II microcontroller available from Parallax, Inc. features the PBASIC programming language and can be purchased with the "Board of Education", which allows solderless connection of sensors and actuators to the microcontroller chip. The company also maintains a website which provides hardware kits and curricula to use with the kits[8].

The "What is a Microcontroller?" curriculum from the "Stamps in Class" website proved to be an appropriate starting point for the development of the DAPCEP mechatronics course. We found that the exercises we adapted from this curriculum provided a good introduction to controlling components like flashing lights and servomotors and reading input from sensors like pushbutton switches and photoresistors. However, assessment data from the earliest offering of this course revealed the weakness that the exercises lacked a capstone-like experience that challenged participants to put all of the components together to create a more complex system. The next step was to work with Parallax's Boe-Bot kit and their "Robotics!" curriculum to allow students to build and program a mobile robot by the end of the course. Participant satisfaction with the course was much higher with the robotics emphasis.

The Spring 2003 offering of the course was conducted in four Saturday sessions, each session lasting 4.5 hours. This scheduling was adopted because the faculty were not available to do six sessions that year. The first two weeks were devoted to an introduction to mechatronics systems and components followed by the design of an automatic door opener, using switches to initiate the door opening, and a photoresistor to sense when it would be safe to close the door. Due to time constraints, we gave students the door mechanism and had them focus on how they would control the servomotor that drove the door mechanism. With more time, we would have asked students to design and build their own door mechanism and linkage to the servomotor. In fact, the Spring 2004 offering of the course (back to six three-hour sessions) adds the design and fabrication of the door mechanism. The last two weeks of the Spring 2003 offering (three weeks in the Spring 2004 offering) allowed participants to work with the mobile robot described above. Course evaluations from the Spring 2003 offering indicate that students were pleased with the

challenges that the course presented to them. The Spring 2004 offering is underway as this paper is being submitted.

Pre-Engineering Programs for Girls

From the DAPCEP experience with students from underrepresented populations, we moved to offering a Summer Design Institute for Women. This institute, with generous support from DaimlerChrysler Corp., was a week-long program that had modules in areas such as computer-aided design, rapid prototyping, robotics, and mechatronics. In the three summers this program ran, about 45 young women participated.

The mechatronics module of this institute was designed to flow from other institute activities. Specifically, the students participated in a module about mechanical design and solid modeling, learning how to use CAD and a rapid prototyping machine to create a door linkage for an automatic door similar to the one described above. In the six-hour mechatronics module they then used the parts created on the rapid prototyping machine to link a servo motor to a sliding door that was provided to them, and wrote the program to control the motor and thus the opening and closing of the door.

Here are some of the comments the 2000 participants in the Summer Design Institute for Women made about their Mechatronics course:

- "Cool!"
- "It was fun when I finally learned how to program",
- "Very interesting",
- "I thought the programming was very interesting and I liked how he had the notes already prepared, it made it a lot easier to understand".

Of the eleven participants who completed an evaluation that year, this course scored a 4.0 on a 1-5 scale when asked how interesting and informative the Mechatronics course was.

The Summer Design Institute was replaced beginning in 2002 with STEPS (Science, Technology, and Engineering Preview Summer Camp for Girls), a week-long residential program sponsored by the Society for Manufacturing Engineers, Ford Motor Company, and other corporate sponsors. The STEPS Program at the University of Detroit Mercy is based on the design, construction, and programming of an autonomous vehicle that uses light to navigate and avoid obstacles. The idea came from the earlier success with mobile robots in the DAPCEP course. In the summer of 2003, three groups of about 40 girls each spent a week living on campus and engaging in experiential learning about the engineering and science fields that pertain to the mobile robot they work on through the week.

In preparation for the construction of the robot, the participants learned about the scientific and engineering principles necessary for robotics design through the use of 90-minute hands-on learning modules. Two modules were created to provide the necessary background in mechatronics design. The first module introduced the students to the Basic Stamp II microcontroller and the control of servomotors. Another module on sensors used the same microcontroller to introduce students to two different sensors, a photoresistor and an ultrasound sensor. On Thursday of the camp, robots were assembled, calibrated, and tested. These

autonomous vehicles used light to navigate and avoid obstacles, and photoresistors were used as sensors.

STEPS Into High School Program

As a result of their involvement with the STEPS Program, Ford Motor Company wanted to bring the STEPS experience to more students in Detroit area high schools. The STEPS into High School (SIHS) Program introduces students to manufacturing, and electrical & mechanical engineering through a series of field trips to the University of Detroit Mercy and one to Focus:HOPE. Students build their own robot with the help of Ford engineers and University students, staff & faculty. Suggested activities allow teachers to integrate the SIHS program into their regular curriculum in areas such as pre-engineering, CAD, science, and math. The SIHS curriculum was offered at 2 area high schools in the 2002-03 academic year, and is being conducted with 10 more schools in the 2003-04 academic year.

By all accounts, the six schools that have completed the program as of March of 2004 have given extremely positive reviews. The students overall were genuinely appreciative of the opportunity and walked away with a much greater understanding of engineering. The Boe Bot kit from Parallax provided the perfect model for our program activities. Each school received two Boe Bot kits at the conclusion of the program to take back to their school. In addition, the four high schools which completed the program between September and December of 2003 are being mentored by engineers from Ford Motor Company (two engineers per school) in "Phase II" of the SIHS which will use the actual Boe Bot kit to compete in a Ford-designed competition.

Here is a synopsis of the activities that comprise SIHS:

Week #1 – CAD and Rapid Prototyping

Students will receive a 90-minute introduction to CAD using I-DEAS. They will have the opportunity to design wheels for the STEPS robot. They will then learn how to create an assembly with their base and wheels along with a pre-designed motor and brackets. Parts created in I-DEAS can be produced using rapid prototyping. Through this process, students will see how their ideas can quickly be turned into reality.

Possible Prep Activities/Discussion Topics:

(1) If your school has a CAD lab, have the students visit it prior to this field trip.
(2) What is a CAD system? What is it used for and how? How does something modeled in a CAD system become a real physical product that you can buy/use?
(3) Research rapid prototyping on the web. What is it? How does it work?

Week #2 – Manufacturing

In the first hour, students will manufacture the wheels for their robot. They will work in the College's machine shop, and use a vertical band saw, lathe and sander to turn raw plastic material into wheels.

In the next half-hour, they will get a brief introduction to CNC machining. An aluminum base for the robot will be produced right in front of them.

In the last half-hour, students will mount their wheels to the motors and then the motors to the base.

Possible Prep Activities/Discussion Topics:
(1) What does CNC stand for? Research how a CNC machine works on the web. What math concepts are important in CNC machining?
(2) Motors Lab (provided to the participating schools)

Week #3 – Focus:HOPE
Focus:HOPE is a nationally recognized civil and human rights organization in Detroit, Michigan. Their mission is to use intelligent and practical action to fight racism, poverty and injustice. It is also home to a successful machinist training institute and manufacturing facility.

The purpose of this trip is to expose students to manufacturing on a large scale. They will visit the Center for Advanced Technologies.

Possible Prep Activities/Discussion Topics:
(1) Watch the Focus:HOPE video

Week #4 – Electronics
During this field trip, students will assemble the electrical components on their robot. This includes building the circuit on the main board (using wires, resistors, sensors and capacitors), connecting the secondary board to the main board, connecting the motors and then connecting the batteries.

They will then download the program that verifies that the sensors are working properly.

Students will also create a cover for their robot using vacuum forming.

Possible Prep Activities/Discussion Topics:
(1) Research circuits. What is a circuit? What are resistors and capacitors? What is a light sensor and how does it work?
(2) Battery Lab (provided to the participating schools)
(3) Circuit Lab (provided to the participating schools)
(4) Research vacuum forming on the web.

Week #5 – Programming, Final Testing
During this field trip, students will download a sequence of programs that are used to verify that the motors are working properly and to synchronize them with the main program. The last step is to download the main program that guides the robot through darkness using a sequence of lights.

Obviously, some resources are required to conduct this program successfully. Ford Motor Company has encouraged a number of its engineering personnel to work with an assigned high school as a community service project. It has also provided funding to purchase the components of the robots and to hire a student assistant who provides technical support to the high school

teachers and volunteer engineers. The Director of Pre-College Programs for the College of Engineering and Science (Dan Maggio) provides the coordination and scheduling functions.

Project Timeline

The table shown below provides the schedule of offerings of these pre-college outreach programs from the beginning. Note that the DAPCEP program as a whole began much earlier, and that the table indicates the first offering of the DAPCEP mechatronics course. The first offering of each of these programs was preceded by approximately two to three months of development and planning. The planning for subsequent offerings of each program also starts several months in advance, but the development time is greatly reduced for repeat offerings, as the development is limited to program improvements that do not require starting from scratch.

Program	***Program Offerings***
DAPCEP	• March-April 1999 • March-April 2000 • March-April 2001 • March-April 2003 • March-April 2004
Summer Design Institute for Women	• June 1999 • June 2000 • June 2001
STEPS	• June 2002 • June-July 2003 • June-July 2004
STEPS in High School	• September 2002-present

The Mechatronics Road Show

Currently the SIHS program brings the high school students to the UDM campus for CAD, parts fabrication, and robot assembly, programming and testing. Scheduling this many field trips may not be feasible for some schools, and travel to campus is not a necessity for this program to succeed. Here we outline a strategy for the successful implementation of SIHS on site at a high school.

Week 1 activities: The CAD portion may take place in the high school's computer lab with the help of the school's drafting instructor. Since many schools do not have rapid prototyping capability, a short video could show the students how their part would be made after they produce the CAD drawing. If the school does not have a CAD lab and instructor, a field trip to UDM would be needed.

Week 2 activities: If the school has a machine shop, students could make the wheels on site with the help of the shop instructor. If not, then partially fabricated wheels could be provided to the school for finishing by the students with whatever hand tools are available. The CNC machining demonstration could be made into a video, and the finished aluminum bases for the robot could be provided to the schools. Parallax makes a complete robot kit, called the Boe-Bot (used in the

DAPCEP course described earlier), which comes with its own chassis and all the parts that we fabricate either in the machine shop or on the rapid prototyping machine. This chassis is smaller than the one used in the SIHS program, and cannot accommodate some of the extra parts (e.g., serial servo controller, extra battery) that we have used to enhance the performance of the robot. Nevertheless, this kit would still provide an exciting project for the students who work with it.

Week 3 activities: A field trip to see first-hand a full scale manufacturing facility is still recommended. However, this visit is not critical to the operation of the robot itself, and could be made optional.

Week 4 activities: The wiring of electronic components on the robot could easily take place at the high school with the help of the science teacher and Ford engineers. The use of a soldering iron may be needed to assure good connections. Unless the school has vacuum forming equipment, the cover for the robot will either have to be optional or made in some other way. During this week, the students are introduced to the Basic Stamp II microcontroller, which they use to test the photoresistors. The Basic Stamp Editor runs on any Windows PC, and only a serial cable is needed to interface with the microcontroller, so the testing of the photoresistors may take place on site at the high school.

Week 5 activities: Programming and testing may take place at the high school because the programming setup from Week 4 should already be in place. Some basic hand tools and a soldering iron will suffice for any adjustments or modifications to the robot needed to make it perform properly.

Taking the SIHS program "on the road" means that the scheduling of the program at different high schools may overlap, as most if not all of the activities take place away from the UDM campus. Some coordination will still be needed to manage the workload intensity of the student assistant. If a number of schools conduct their programs simultaneously, one or more additional student assistants may need to be hired, and additional components will have to be purchased. (Currently, components such as microcontrollers and servo motors are salvaged from the vehicles for re-use by the next school.)

The mechatronics activities described in the other programs are also modular and can easily be taken on the road. For example, a set of 8 Basic Stamp II microcontrollers, DC power adapters, serial cables, servo motors, and electronic components such as LEDs, switches, photoresistors, and ultrasound sensors fit in a compact toolbox on wheels that can easily be taken to a high school or Girl Scout meeting for a hands-on mechatronics experience, provided that computers are available for writing the programs. A brief introduction to mechatronics with a hands-on exploration of microcontrollers, sensors, and servomotors can be completed in about 2 hours. The activities may be expanded to fill more time, or limited to use less time. They may also be structured to meet for shorter time segments over a number of sessions, which might be the best format if a high school teacher wants to use the activities in an existing class time slot.

Summary

These pre-college outreach programs have all been highly successful, and the focus on women and underrepresented minorities in DAPCEP, the Summer Design Institute for Women, and the

STEPS Program has been a big draw in attracting corporate and further grant support to continue the programs. The mechatronics content has helped to enhance corporate interest because of its relevance to the auto industry in Detroit. The modules that have been developed can be adapted in various configurations to allow faculty to take the show on the road and offer anything from a two-hour hands-on introduction to mechatronics up to a six or more week series of activities.

References

[1] "Mechatronics: A Comprehensive, Interdisciplinary Curriculum Development Initiative", National Science Foundation Grant No. DUE-9950862.

[2] S. A. Yost, S. Das, M. Krishnan, "Mechatronics: A Comprehensive, Interdisciplinary Curriculum Development Initiative," *1999 Frontiers in Education Conference Proceedings (FIE '99)*, p. 13a1-1, San Juan, PR, Nov. 1999, p 13a1-1

[3] M. Krishnan, S. Das, S. A. Yost, "Team-Oriented, Project-Based Instruction in a New Mechatronics Course," *1999 Frontiers in Education Conference Proceedings (FIE '99)*, pp. 13d4-2 to 13d4-6, San Juan, PR, Nov. 1999, p 13d4-1 - 13d4-6

[4] S. A. Yost, "Introducing Mechatronics in a First-Year Intro to Engineering Design Course," *ASEE 2000 Conference Proceedings*, St. Louis, MO, June 2000

[5] S. A. Yost, A. S. Hoback, "A Team Approach to Interdisciplinary Instruction in a First-Year Engineering Design Course," ASEE North Central Section Spring Conference Proceedings, Lansing, MI, March 2000

[6] S. A. Yost, "Taking Mechatronics on the Road," *Proceedings, 2002 SWE National Conference,* Detroit, MI, October 2002.

[7] "New Course Development in Advanced Mechatronics", National Science Foundation Grant No. DUE-0309719.

[8] Parallax, Inc. www.parallaxinc.com (corporate website), www.stampsinclass.com (curricula, educational materials). Accessed February 27, 2003.

Biographical Information

SANDRA A. YOST is an Associate Professor in the Department of Electrical and Computer Engineering at the University of Detroit Mercy, and Co-Director of the Women's Studies Program. She is a Past Chair of the North Central Section of ASEE and is currently Zone II Chair-Elect. Dr. Yost earned a Ph.D. in Electrical Engineering from the University of Notre Dame in 1996.

DANIEL D. MAGGIO is Director of Pre-College Programs for the College of Engineering and Science at the University of Detroit Mercy. He has directed many successful outreach programs, including the summer STEPS (Science Technology Engineering Preview Summer camp for girls) and the College's annual Technology Discovery Day. Maggio is also an adjunct instructor in the Department of Mathematics and Computer Science.