
AC 2011-1737: HIGH-TECH TOOLS FOR FRESHMAN ENGINEERS

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High Tech Tools for Freshman Engineers

First year engineering programs and retention

While Science and Engineering capacity has increased across the globe and greater cross-border collaboration has been made possible due to the availability of a larger pool of researchers, this presents challenges to U.S. competitiveness in high technology areas and to its position as a world leader in critical S&E fields. Within the US the proportion of Natural Sciences and Engineering (NS&E) degrees as a share of total degrees conferred in US has declined by approximately eight percent from 2002 to 2007^[1]. There is evidence to suggest that some of this decline can be attributed to the student attrition during their first one or two years from the science and engineering programs.

Previous studies have indicated that significant student attrition or “switching” from science and engineering educational programs to other fields occurs during the first one or two years of college^[2], making the first year college experience for students a critical one in the choice of their careers. Several models have been used to describe the attrition of STEM students including a leaky pipeline model, a path model, and statistical models based on pre-college characteristics for incoming freshmen as indicators of their future retention in engineering programs^[3]. However, it should be noted that one of the important research studies suggests that proportion of students switching (40%) because of “inadequate preparation in high school math and science” is almost equal to the proportion of “non-switchers” (38%) reporting inadequate preparation in those subjects^[2]. This suggests that although inadequate preparation in Mathematics and Sciences in the high school is one of the major reason for switching, it does not mean that the non-switchers who remain in the programs are more comfortable with their level of preparation and their reasons for their “staying the course” may not be related entirely to their superior preparation. In an ethnographic study^[4], additional reasons cited for switching to non-Science, Math or Engineering (non-SME) disciplines were a lack or loss of interest in science; a belief that a non-SME major holds more interest or offers a better education; and feeling overwhelmed by the pace and load of the curriculum demands. Retention of entering freshmen to completion of their engineering degrees could increase the number of engineers graduating in a given year by as much as 40 percent.^[5]

Unlike the fields of Law, or Medicine, an undergraduate degree in engineering is the first professional degree for engineers^[6] after which they are expected to go to work with skills and demonstrate flexibility while working in a demanding and complex environment. Studies of most engineering curricula indicate a very high workload in the freshman year that consists of essential science and mathematics course sequences with scattered engineering design experiences or introduction to engineering seminars. The courses taken during a typical freshman year in electrical engineering at UMASS Lowell are listed in Table 1.

Table 1 Typical Freshman Engineering Courses

Freshman Year Course Category	Credits Received
Introduction to EE	1
Introduction to Engineering (2 credit/semester)	4
Social Science Elective	3
English/College Writing/	6
Calculus	8
Engineering Physics	8

Typically university engineering students spend nearly eighty percent of their freshman year taking courses that are not directly linked to their chosen profession of engineering. They may not receive mentoring by engineering faculty or have opportunities to solve engineering problems in a laboratory with sophisticated engineering tools and thus develop an appreciation for the engineering profession. The contact of community college engineering students with the engineering profession is often even more meager.

Engineering programs at two-year institutions

Nearly forty percent of engineers who graduated between 1999-2000 attended a community college at some point during their studies^[7]. Despite this broad contribution of community colleges in our engineering education system, the equipment and financial resources available to these two-year undergraduate institutions remain considerably less than that of their four year institution counterparts. In addition, due to the lack of resources or time, community college faculty members may not receive the opportunity to advance their knowledge in their respective fields through professional development or to bring in updated professional knowledge to their classrooms. Community college students may not receive the benefit of the resources and meaningful freshman engineering experiences. Engineering programs in most community colleges have curricula heavy in non-engineering courses during the first two years, giving the students even fewer opportunities to interact with their engineering faculty than their counterparts at the four year institutions. This puts the engineering programs in community colleges at considerable risk of losing students due to lack of early engagement in their chosen field and negatively impacts their graduation or retention rates.

It can be expected that community colleges will continue to attract engineering students for the educational support and lower costs of the educational programs, and this will continue to influence the overall engineering retention rates of US institutions as a whole. The impact of community colleges in preparing future engineers may warrant additional support for faculty professional development and early student engagement. Fostering meaningful collaborative partnerships between local four year institutions and community colleges and building the capacity of community colleges can help to better serve this student population.

Influencing change in undergraduate education at the community college

A five-year National Science Foundation Science, Technology, Engineering and Mathematics Talent Expansion – University Partnership (STEP UP) grant allowed Massachusetts Bay

Community College (MBCC), Northern Essex Community College (NECC), and Middlesex Community College (MCC) in Massachusetts to partner with Northeastern University's Center for Subsurface Sensing & Imaging Systems (CenSSIS) to increase student participation in the Science, Technology, Engineering and Mathematics (STEM) programs. This grant laid the foundations for building bridges between community colleges and research institutions, for aligning courses and curriculum, and resulted in increased opportunities for the community college faculty and students to participate in summer Research Experience for Teachers (RET) and Research Experience for Undergraduates (REU) programs. The NSF grant has also been successful at positively impacting the communication among the institutions and the availability of resources.

In the summer of 2010, with financial support from CenSSIS, faculty members from the three community colleges involved in STEP-UP were invited to participate in a two-week professional development workshop on engineering problem solving and computation held in Northeastern's High Tech Tools & Toys Lab (HTT&TL). HTT&TL is first-year engineering laboratory course at Northeastern which immerses students in engineering problem solving and discovery by giving the students access to sophisticated engineering tools during their freshman year. The intensive two-week training/workshop for the community college faculty led to broader discussions on the applicability of the course to engineering students at community colleges and to collaborations to replicate, adapt, and test the course modules at the community colleges.

Introduction of a new course at a community college requires the course to be passed through the governance processes in the college, thus requiring more time for implementation. The lead time to adoption of the learning modules in the engineering curriculum at MBCC was reduced since during the first three years of the STEP UP grant MBCC was able to conduct program reviews and realignment of the engineering curriculum with the curricula of four year colleges. In the realignment, it was decided to not expand the curriculum by introducing an additional course. Rather it was decided to eliminate courses such as Thermodynamics (usually taken in the third year at a four year institution) from the second year of the curriculum at MBCC. This provided an opportunity to include a new course on "Engineering Computation with Application Software" aligned in goals and outcomes with the GE 1111 Engineering Problem Solving and Computation course that is offered at Northeastern University for their freshman students. This course has been designed to transfer either as a programming class or as an Introduction to Engineering course with a hands-on laboratory. It does not assume any previous programming background and requires only a Pre-Calculus background, although some students may have taken Calculus I in their first semester at MBCC.

Engineering Computation is being taught at Mass Bay Community College with significant contribution of resources and expertise from Northeastern University (NU). While this course is similar to the course at NU, the implementation of this course at a community college is novel as it represents a strong commitment of all the institutions involved in creating engaging curriculum at a community college. The collaboration is synergetic, since all partner institutions have a complementary and unique role in the process: with Northeastern providing the expertise, funding, and training/capacity building; with one community college partner, NECC, coordinating the production of the low-cost equipment and another community college partner, MBCC, implementing and testing the modules in a new course and measuring learning

outcomes. NU also facilitated an academic support award of MATLAB[®] software along with the MATLAB[®] Data Acquisition and Instrument Control toolboxes to the community colleges for the development of the courses. The first course implementation at MBCC created a broader impact as it served to guide the other two community colleges who are currently designing similar courses for their engineering curricula and the broader academic community.

Pedagogical strategies

In most traditional classrooms, the instructor delivers information and the students receive it mostly as passive learners. In contrast, it has been suggested that "approaching teaching of physics as physics experiments" would allow the knowledge transfer to take place with a higher opportunity for retention of the concepts and ideas, taking advantage of useful new technology^[8]. Faculty at the three community colleges have always attempted to achieve a balanced, active learning style in their engineering courses and enthusiastically embraced the approach utilized at NU. HTT&TL allows freshman engineering students to use sophisticated modern tools at a very early stage to create engaging and stimulating learning environment. At MBCC, we have used an approach where students do not need to be independent learners at the start, but learn to take greater responsibility as they progress.

The new course offered at MBCC is a freshman year (second semester) 4 credit course, and is designed to create a novel and engaging engineering laboratory environment in which first year engineering students learn programming in MATLAB and C++ by using low-to-moderate-cost high-tech tools such as sensors, stepper motors, spectrometers, data acquisition systems, and instrument control toolboxes. Students learn to write programs that control the equipment and simultaneously observe engineering tools at work. MATLAB is a widely used software package and engineering programs at most transfer institutions require at least one course in MATLAB or C++ programming. MBCC chose MATLAB as the primary high level computing language for instruction as it is widely used in four year institutions, allows the students to acquire, manipulate and visualize the data quickly, and enables students to test their programs easily.

Examples of experiments used for instruction in the course at MBCC are stepper motors attached to lightweight dial gages controlled from the MATLAB environment; spectroscopic discrimination of olive oil from soy oil, corn oil, and motor oil; imaging, color recognition, and sorting of painted ping-pong balls with a video-cam. The modules have been chosen so they can present a variety of interesting engineering problems to the students and can be assembled in a workshop using low cost materials such as Plexiglas and lightweight stepper motors. As part of this effort, NU provided six Thorlabs optical spectrometers (CCS 100), OSL1 (High Intensity Fiber Light Source), NI DAQ 6008 USB units, and the software and routines needed for data acquisition (MATLAB, C++ and NI Labview/Visa) to MBCC. The one-time cost of the implementation for experiments that would support 12 students was approximately \$20,000. The setup is simple to assemble and can be stored in a small cabinet. Mathworks, Inc. donated MATLAB[®], and its Data Acquisition and Instrument Control toolboxes to MBCC and other two community colleges through collaboration with NU. To keep the cost of the experiments low, and to encourage broader participation of students interested in STEM careers, NECC worked with an Electronics class at Whittier Regional Vocational Technical High School in Massachusetts whose students fabricated the dial gauges with photocells and the control boxes that supply the required power to the motor and control the direction of movement of the flag

attached to the dial gage.

The course does not assume any previous programming/computing background and requires only Pre-Calculus as a pre-requisite. Therefore during the first four weeks of classes, students were provided careful guided instruction on using the MATLAB command window and on learning about different data types and variables till they become familiar with the environment. Students were given in-class instructor-guided exercises for nearly four weeks to teach basic MATLAB commands as well as to familiarize them with matrices. Students learned to work with arrays as well as loops, conditional branching, and functions. The problems included problems from finance, transportation and energy data, and geometric figures. Students were also introduced to the idea of treating an image of a NASA astronaut as a matrix, manipulating it in MATLAB while introducing elementary matrix manipulations that allow the students to experiment with the image while learning from it. Students are also given basic instruction on using C++ programming language to write simple programs.

After about four weeks, students started using the tools and control equipment by writing small, simple programs. Students were given handouts designed carefully so they are presented with all the necessary information and, through a series of small tasks and goals, are guided slowly into becoming more independent learners. During the course of time, students are expected to gain confidence in handling small equipment safely, write simple programs, and strengthen their analytical abilities. Students are expected to write and document their programs and participate in classroom discussions. The evaluation strategies include emphasis on approach to problem solving, laboratory submissions, in-class exams. This is an ongoing investigation and, while the qualitative comments of the students have been very positive, student engagement and the impact on their awareness of engineering careers will be assessed from self-reported student satisfaction and from surveys of level of comparative learning with their prior classes. The surveys are in progress and will be reported later.

Course modules

Some of the experiments (lab modules) that are being implemented at the community college among others at the Community college are described. The software routines as well as the manuals for these experiments were developed at NU.

Experiment 1, Control of a Stepper Motor, uses a control box, a stepper motor on a mount, an indicator flag mounted on the motor shaft, a protractor attached to the face of the mount, indicating the rotation angle of the flag, two photo resistor cells, light emitting diodes (LEDs) mounted near the respective photo resistors and National Instruments (NI) USB2008 A/D module, MATLAB software on a PC, including the Instrument Control & Data Acquisition Tool Boxes. In this experiment, the stepper motor assembly is controlled by the NI USB2008 A/D module. An experimental setup is shown in Figure 1.



Figure 1 Stepper Motor Assembly showing a NI USB 6008, a control box, dial gage with flag controlled from the MATLAB Programming environment.

In this experiment, students are introduced to MATLAB and write simple MATLAB programs to move a light-weight indicator (flag) attached to a stepper motor through a series of steps. This is one of the first experiments for students and at this stage students do not need elaborate programming skills required for programming the board. Instead, students use pre-written MATLAB m-files STEP.M, CW.M, and CC.M to control the movement of stepper motor such as causing the motor to rotate clockwise or anticlockwise through given number of steps. Students write loops to move the motor through a number of steps, use a protractor to measure the angle the flag rotated from the original position, and calculate the angle per step from this measurement. Students then estimate the error in their determination and conclude that their measurements are more precise if they use a larger number of steps. The concept of feedback is introduced by having the indicator pass over two photo-sensors monitored by the analog input of the NIUSB6008. Their final program causes the flag to move from an arbitrary initial position to the first photocell, stop, turn on a light-emitting diode, then reverse directions and go to the second photocell position. The program thus includes sequential programming steps, conditional looping (WHILE statements), and a simple threshold test on the photocells.

Experiment 2, Distinguishing Materials by Spectroscopy, uses a Thorlabs CCS 100 optical spectrometer and OSL1 High Intensity Fiber Light Source with a fiber optic sample bench and couplers as illustrated in Figure 2. The hardware expense for this station (without the computer) is about \$3000. The CCS100 is a “no-moving-parts” spectrometer where the incident light is dispersed across a detector array which is downloaded to a computer. MATLAB routines to control the spectrometer were written by an NU graduate student. Students can download and

plot the spectral transmission of materials in MATLAB, and write programs to, for example, distinguish olive oil from corn or soy oil.

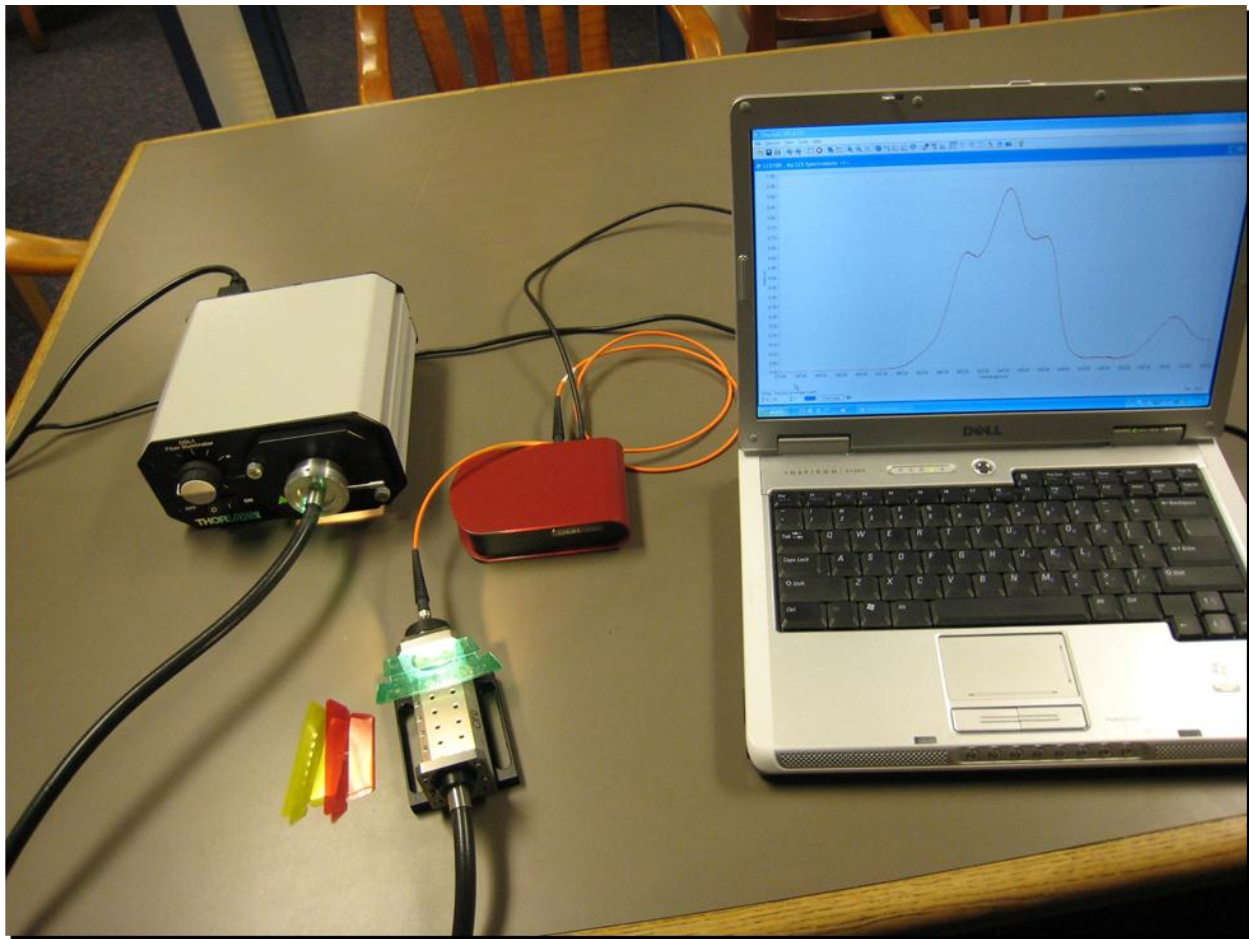


Figure 2 Thorlabs spectrometer (center) with light source (left) optical fiber sample bench and computer output.

Experiment 3, Computer Control of Digital Output Using C++, uses the same stepper motor assembly controlled by the National Instruments NI USB2008 A/D module as used in the first experiment. By the implementation of this lab, students are expected to be familiar with most basic programming ideas. Students learn writing a C++ program to control the digital output of NI USB 6008 and use it to control the stepper motor to rotate through fixed angles and change directions. Students also learn to use functions in the National Instruments Data Acquisition (NIDAQ) libraries to control the outputs. The stepper motor is connected to the calibrated dial and a stepper motor controller in the aluminum box. The controller has two inputs, labeled “Clock” and “Direction.” Students connect the Clock input to a digital output port and the Direction input to another output port. The controller has circuitry to cause the stepper motor to make one step counterclockwise if it receives a single rising pulse in Clock and the Direction input is held at 5V and clockwise if there is a rising pulse on Clock and the Direction input is held at 0V. Students learn to control the movements of the stepper motor by writing a for loop in

C++ and also estimate the torque at which the stepper motor will cease to function as intended and will skip steps.

In Experiment 4, Ping Pong Ball sorting using C ++, students learn how to download an image from video cam and analyze the output to determine the color of a uniformly colored object, such as a ping pong ball, that the video cam is focused on. A small metal stand holds the ping pong ball ready in front of a steady fixed video camera focused on this object as illustrated in Figure 3.

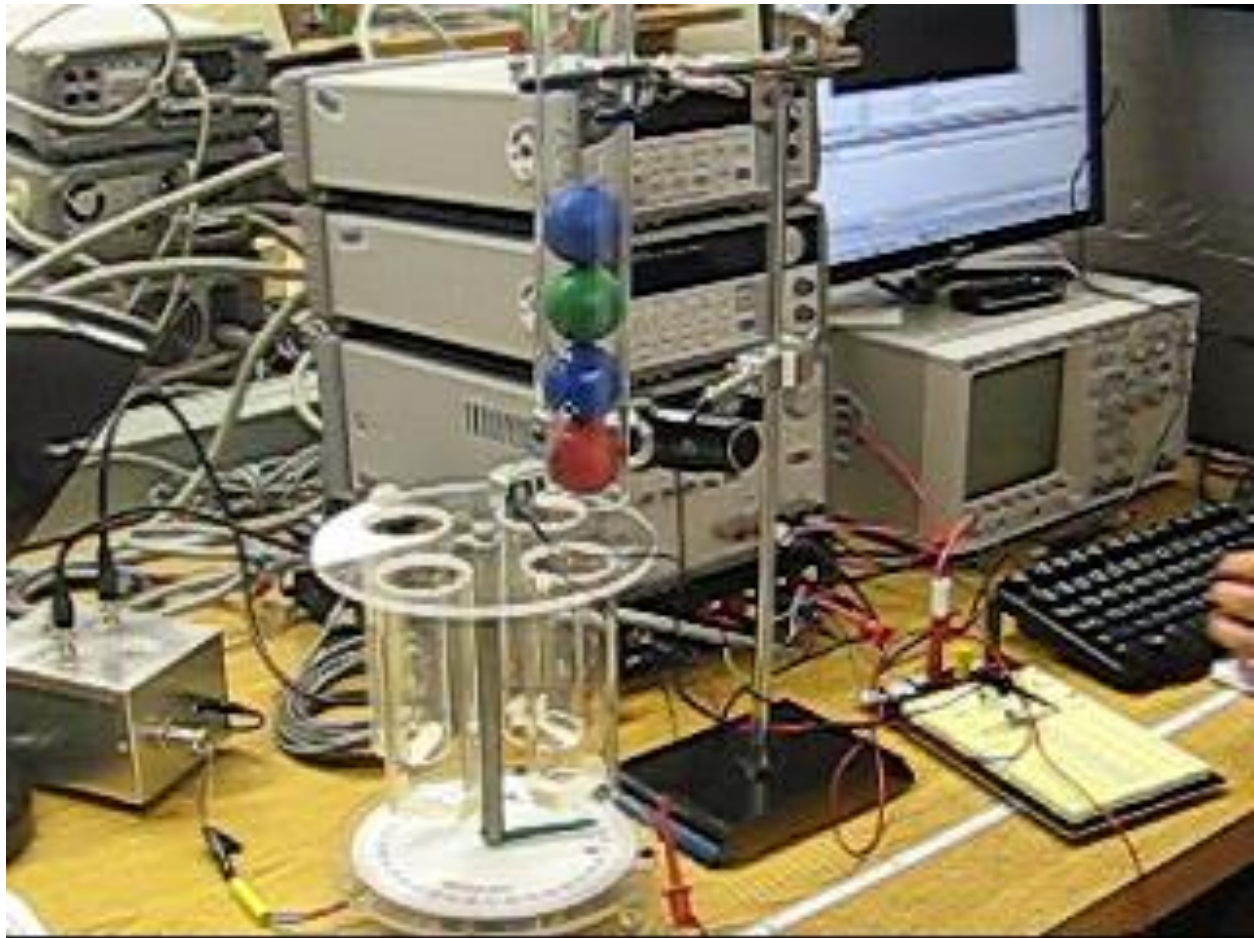


Figure 3 Ping-pong ball color sorting using a videocam and stepper-motor-controlled receptacle carousel.

Students are provided with two C++ functions that help them capture the image of the ball. Students focus on a pixel in the center of the image and identify the color of the object using the R, G, B mapped values for the pixel. For simplicity, students are provided balls with only Red, Green or Blue colors so they can be identified easily. Converting the RGB values to Hue/Saturation/Value parameters allows students to identify the color regardless of illumination conditions by determining the hue angle. The next step of this experiment is to identify color of several ping pong balls and to sort them out into correct slots. A transparent tube holds the balls whose colors need to be identified and a stepper-motor-controlled rotating receptacle holder is positioned under the input column. The video-cam mounted on the ring stand that holds the input column is focused on the lowest ball. Based on the color of the lowest ball, the stepper motor

rotates the appropriate receptacle under the input column and releases the ball to let it fall into the right receptacle.

Assessment

Assessment of the student experience during this course will not be completed until May of 2011. The full results will be presented at the Annual Conference along with the overall student satisfaction from this course. Students will be surveyed about their experiences in the course as compared to similar courses. Students will also be surveyed about their perceived difficulties or lack of preparation; whether or not they enjoyed the experiments; and if taking this course influenced their opinion about the engineering profession. The effects on student retention will be predicted from the self-reported level of student engagement and the impact on their awareness of engineering careers.

Conclusions

An engaging hands-on laboratory course on engineering computation using MATLAB and C++ has been developed at Massachusetts Bay Community College through collaboration between a regional research university, three community colleges, and a regional technical high school. Experiments were designed by community college faculty in collaboration with engineering faculty from the university. Lab equipment for the course was constructed by a technical school under the guidance of community college and university faculty with critical financial support from the university. The educational offerings at the community college were enhanced through the collaboration and the community college provided a test-bed and teaching expertise for implementation of the course. The other two community colleges will incorporate similar modules into their first-year engineering courses during the 2011-2012 academic year. The hands-on courses resulting from this collaboration have the potential to transform the education of future engineers, although longitudinal studies will be required to understand the broader impact on retention and growth of the freshman year experiences.

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