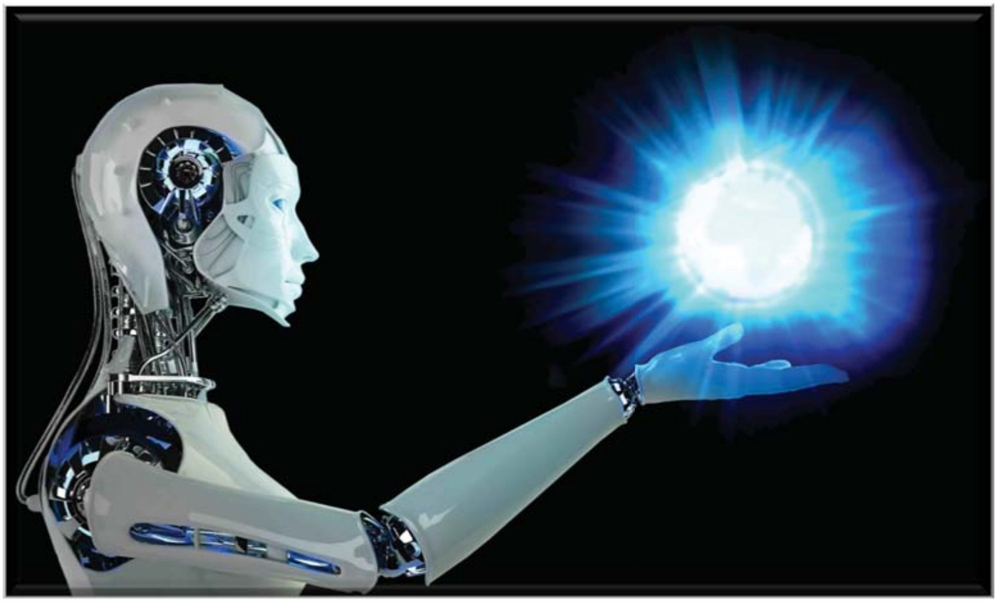
NC STATE UNIVERSITY

UNIVERSITY of NORTH CAROLINA
ASHEVILLE

JEM Curriculum Review and Proposal



MECHATRONICS ENGINEERING…

Engineering for the 21st Century

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Table of Contents

Acknowledgments

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University	Faculty	Department
Bucknell University	Dr. Steven Shooter	Mechanical Engineering
	Dr. Charles Kim	Mechanical Engineering
	Dr. Maurice Aburdene	Electrical Engineering
	Dr. Michael Thompson	Electrical Engineering
	Dr. Joseph Tranquillo	Biomedical Engineering
California State University Chico	Dr. Ramesh Varahamurti	Mechatronic Engineering
Colorado State University Fort Collins	Dr. David Alciatore, PE	Mechanical Engineering
Georgia Institute of Technology	Dr. Amit Jariwala	Mechanical Engineering
University of Pennsylvania	Dr. Tom Cassel	Mechanical Engineering & Applied Mechanics
	Sarah Rottenberg	Integrat. Product Design
	Dr. Jonathan Fiene	Mechanical Engineering & Applied Mechanics
Southern Polytechnic State University	Dr. Chan Ham	Elec & Mechatronic Eng.

Executive Summary

This report presents the findings of a benchmarking project between the Joint NC State College of Engineering / UNC Asheville BSE–Mechatronics Concentration (JEM) and several other programs throughout the country in support for a potentially improved program for the JEM students. In all, six institutions were visited: Bucknell University, California State University Chico, Colorado State University Fort Collins, Georgia Institute of Technology, University of Pennsylvania, and Southern Polytechnic State University.

The history of Mechatronics dates back to 1969–the year Neil Armstrong walked on the moon–and the word *mechatronics* was coined in Japan. The discipline is extremely popular in Europe and Asia and is gaining ground at institutions in the US and, just as importantly, with employers in the US. The history of collaboration in engineering education between the NC State College of Engineering and UNC Asheville dates back more than 34 years to 1980 when the Two-Plus-Two program was established and to the 1998 creation of the BSE (EGM) program. In 2004, the Joint BSE–Mechatronics Concentration (JEM) was established and it was accredited in 2010.

During the establishment of the BSE–Mechatronics Concentration, it was decided that no new courses would be created at that time. Instead, current program offerings from mechanical engineering, electrical and computer engineering, and material science, etc. would be organized into a curriculum that fit the mechatronics model. Since 1998, the curriculum has seen minor revisions including the addition of mechatronic specific design courses and the shift to a joint offering. This model has served well, but it is thought that perhaps it is time to reevaluate the current curriculum.

Bucknell University has a long history of mechatronics in their curriculum. The faculty has found that students who have taken the mechatronics course do a superior job in their senior capstone design project course. The overall thrust was toward a course that focused on system level integration skills and to shift their program from so many "cookie-cutter" laboratories to more open-ended design based experiences that pushed critical thinking skills.

California State University Chico has the oldest ABET accredited mechatronics program in the country, housed in their Department of Mechanical and Mechatronics Engineering. Its official start was in 1998 with 10 students and has grown to over 300 in 2014, graduating approximately 30 Mechatronics majors per year. Their program has a significant design component across the curriculum with over nine courses that include a design experience. In addition, the students are exposed to a rigorous software sequence including programming and algorithm design, logic design, and embedded systems development that include real-time operating systems with embedded controllers.

Under the direction of Dr. David Alciatore, the department of mechanical engineering at Colorado State University Fort Collins took the unique approach of developing an evolutionary sequence to creating a mechanical engineering curriculum that was mechatronics-based. They felt that this approach would be more manageable as they sought to restructure their traditional curriculum with a mechatronics theme. Of note is Dr. Alciatore has written a widely used book *Introduction to Mechatronics and Measure Systems*, which is used in our ECE 456 course. Their intent was to create *a curriculum with contemporary emphasis, enhanced content, and improved sequencing and coupling of traditional topics including modeling and analysis, computing, electrical circuits and machines, measurements and instrumentation, control theory, and design* with design and computation playing a leading directional role.

In March of this year, I attended the NCIIA Open Conference and met Dr. Craig Forest from the Georgia Institute of Technology. Dr. Forest is in the Mechanical Engineering Department and he gave a talk on the program he spearheaded called the Georgia Tech Innovation Studio. The program boasts several unique operating procedures. Dr. Forest invited me to visit and introduced me to Dr. Jariwala who is the new director of the Innovation Studio. During the visit, I found out they have a long-standing tradition in mechatronics engineering and have developed three courses and built a substantial instructional laboratory for mechatronics, which I toured. The three courses are ME 4405: Fundamentals of Mechatronics, and ME 6405: Introduction to Mechatronics, and ME 6408: Advanced Mechatronics (graduate).

The University of Pennsylvania Department of Mechanical Engineering and Applied Mechanics has a unique relationship between engineering entrepreneurship, product design, and mechatronics. Dr. Cassel founded the engineering entrepreneurship program in 1999 after a successful career as both an engineer and entrepreneur. Sara Rottenberg is the Associate Director of the Integrated Product Design Program at the University of Pennsylvania, a Master's Program bringing together design, business and engineering, and a Lecturer in the School of Design. Dr. Fiene is a Senior Lecturer in MEAM, Director of Laboratory Programs and he is responsible for their mechatronics courses MEAM 410/510. Together, these three have heavily influenced the curriculum trajectory toward design-based experiential learning.

Mechatronics has been in MEAM for nearly ten years. Dr. Fiene has been responsible for growing and running the sequence for more than seven years, relying heavily on his work at Stanford. The course is an elective and is lab/practice based. The laboratory is open 24/7 with 30 stations, but the students can do work at other locations. They also borrow laboratory time and equipment from other areas including CAD software, eight MakerBots, two high-end 3D printers, and four laser cutters, which are all highly utilized.

The Southern Polytechnic State University ABET accredited Mechatronics program is very multidisciplinary with collaboration from mechanical engineering, electrical engineering, computer science, and mechatronic engineering. Dr. Chan Ham stated they have a current enrollment of approximately 250 students. Their graduation rate is quite high and they boast a 95% employment rate at graduation. The students are sought after due to their system-level perspective and they typically move into technical lead positions in a much shorter span of time compared to those in other disciplines.

The Joint BSE–Mechatronics Concentration (JEM) offered at UNC Asheville is a joint offering of NC State University College of Engineering and UNC Asheville. It is an amalgam of courses taught by faculty at UNC Asheville and by faculty at NC State University through online distance education. The amount of courses taught by each institution is roughly a 50/50 split. There are approximately ten courses (32 hours) taught by Electrical and Computer Engineering, nine courses (27 hours) by Mechanical Engineering, and one course (3 hours) by Materials Science. UNC Asheville faculty teaches the remainder of the core sciences, mathematics, and humanities. Currently, there are 124 credit hours required for the degree

Of the six institutions visited, California State University Chico and Southern Polytechnic State are the most closely aligned with our joint BSE-Mechatronics. The other four institutions offered examples of best practices in specialized mechatronics courses designed to introduce students to the discipline and how one institution used mechatronics to realign their mechanical engineering curriculum around design-based experiences for their students.

On many fronts, the Joint BSE–Mechatronics Concentration compares favorably to other programs. Our students are sought after by industry and do well in their careers. Our principle areas for potential improvement surround added competencies in embedded systems and real-time operating systems, and in design-based experiences. With some minor curricular changes, we can make a significant improvement in preparing our mechatronics students for the workforce of tomorrow.

My recommendation is that we consider small, yet important, revisions to the curriculum and these be done to enhance the design-based experience for the students. With the exception of adding a CAD class in the second semester freshman year, the first two years of study would remain unchanged with all changes occurring in the junior and senior years. These proposed changes would move the required credit hours from 124 to 128.

Introduction

Benchmarking is a quality assurance technique used to compare performance of one entity or organization to similar ones. It can be used as a tool for continuous improvement and has been defined by Jackson and Lund (2000) as, "*a learning process structured so as to enable those engaging in the process to compare their services/activities/products in order to identify their comparative strengths and weaknesses as a basis for self improvement and/or self-regulation*."

Part of the benchmarking process includes the identification of appropriate indicators and potential areas for improvement. These could be perceived good/best practices in a specific area or some other quantitative measure based on achievement. In addition, data must be collected to do the comparisons in order to establish priorities for change, resource allocation, and strategic and tactical goal setting.

This report presents the findings of a trial benchmarking project between the joint NC State College of Engineering / UNC Asheville BSE–Mechatronics Concentration (JEM) and several other programs throughout the country in support for a potentially improved program for the JEM students. This trial benchmarking project had the following objectives:

- To begin to develop knowledge and experience of other programs
- To compare programs, processes and identify good/best practices
- To identify possible areas for improvement to the program.

The report presents:

- The background and context for initiating the project
- Comparative information on programs
- Identified strengths and weakness

The report also includes Recommendations to the Course and Curriculum Committee, providing direction for evolutionary change to better meet the needs of the undergraduate students in the JEM program.

Background & Context

The history of Mechatronics dates back to 1969–the year Neil Armstrong walked on the moon–and the word was coined in Japan. The discipline is extremely popular in Europe and Asia and is slowly but surely gaining ground at institutions in the US and, just as importantly, with employers in the US. The fruits of the discipline permeate our lives from haptic technology to Boeing 787 Dreamliners and smartphones to MRI machines. Opportunities for our graduates are as diverse as the movie making industry to semiconductors and music to robotics.

The history of collaboration in engineering education between the **NC State College of Engineering** and **UNC Asheville** dates back more than 34 years to 1980 when the Two-Plus-Two program was established. The first NC State class was offered in Fall 1981 with the official Memorandum Of Understanding (MOU) signed between the universities in May 1982.

From 1982 until 1998 only the Two-Plus-Two curricula were offered. Historically, UNC Asheville provided the largest and strongest source of transfer students to NC State with approximately 325 students to date. The average was fourteen transfers per year, but this has dropped off to an average of seven per year due to the establishment of the BSE–concentration Mechatronics. The first Distance Education course was offered in fall 1996 with UNC Asheville serving as the NC State remote site for early work with MBone and various other delivery technologies.

From 1998 to 2004, the collaboration included the Two-Plus-Two and BSE–Mechatronics Concentration (EGM)–non-joint. The idea for the BSE–Mechatronics Concentration was based on a feasibility study that was conducted between 1996 and 1997, which involved numerous stakeholders including local industry. The study demonstrated industry and student interest in electrical, mechanical and civil engineering. It was assessed that the Mechatronics curriculum would meet the electrical and mechanical engineering needs within a single degree.

The BSE–Mechatronics Concentration was established Fall 1998 with the first junior level class being offered the same year. The two universities signed the MOU in April 1999 and the first EGM graduates were in May 2002. The program was ABET accredited in 2005. The program was formally terminated in 2010 due to the establishment of the Joint BSE–Mechatronics Concentration (JEM). Note that from Fall 1999 to Spring 2004, the program saw 66 admitted students with only a 25% attrition rate.

In 2004, the Joint BSE–Mechatronics Concentration (JEM) was established with the MOU signed between the two universities in March 2004. JEM was accredited in 2010. As of Fall 2014, there are 74 active majors. JEM and EGM boast 96 graduates. We are anticipating 18 JEM graduates in AY 2014-15 and our 100th BSE graduate in December 2014. Currently, 20 Distance Education (DE) courses are offered with DE delivery of coursework being the backbone of the programs. Laboratories and design courses are taught live and locally.

Enrollment in the combined Two-Plus-Two and BSE for 2014 has increased significantly. Incoming freshmen numbers have doubled from 2012-13 to 2013-14 from 62 to 129. We anticipate the incoming freshmen levels for 2014-15 to match those of 2013-14. This increase was first observed in the enrollment of E 101 (see Figure 1 below).

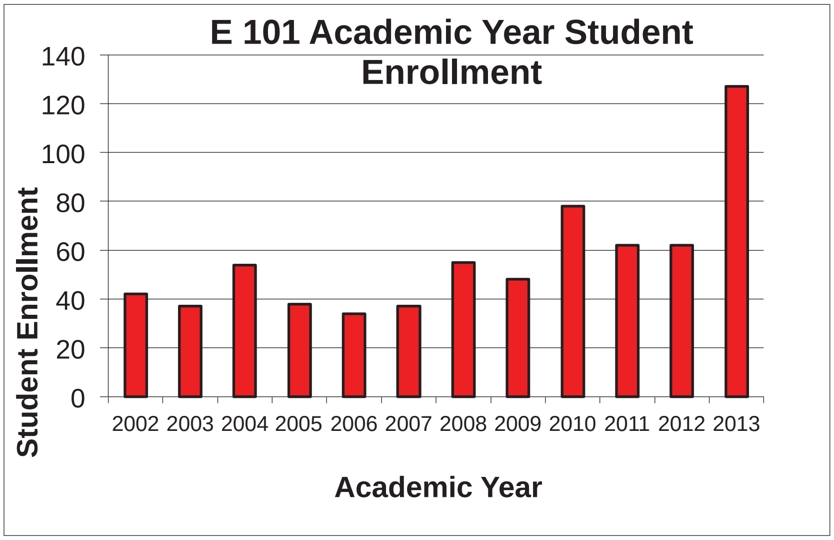


Figure 1

Academic Year	Fall	Spring	Summer
1996-1997	63	14	
1997-1998	73	24	
1998-1999	78	23	
1999-2000	91	55	18
2000-2001	91	51	9
2001-2002	93	55	
2002-2003	88	50	
2003-2004	72	56	1
2004-2005	81	66	
2005-2006	93	59	
2006-2007	112	65	
2007-2008	87	80	
2008-2009	95	61	
2009-2010	96	70	
2010-2011	131	97	3
2011-2012	124	105	7
2012-2013	133	128	5
2013-2014	178	170	15

Table 1 Headcount Data

We also observed a higher than average yield in E 101 students planning to pursue engineering out of E 101. In Fall 2012, 78% of students planned to pursue engineering. These two factors together have served to increase the enrollment in subsequent classes as well. This can be seen in our Headcount Data (see Table 1).

The current GPA threshold for declaring a BSE – Mechatronics Concentration major is 3.0. Since this was raised from 2.5 in August 2012, there seems to be a higher overall caliber of students in the program compared to previous cohorts.

In 2012-13, we saw **23** students matriculated to the BSE degree. In 2013-14, this number increased to **35** students matriculating to the BSE degree. This reflects the overall increasing trend associated with our increasing enrollment. The previous two- year period saw 18 students matriculated each year.

In 2012-13 there were seven JEM graduates and all were employed by August of 2013 with an average starting salary of $62,000. In 2013-14 there were 12 JEM graduates and 1 (the final) EGM graduate. All were employed by July of 2014 with an average starting salary of $62,300.

A recent review of our graduates yielded the following:

89% are working in engineering;
6% are in graduate school;
5% are unemployed or out of contact.

2014 marked the establishment and first award of the Hallie Sheaffer Award for Excellence. The award was established in honor of Hallie Sheaffer, JEM '14, for her outstanding academic achievement. The inaugural award was given to Dakota Lazenby, JEM'14, for his outstanding academic achievement. The LORD Corporation, employer of Hallie Sheaffer, sponsors the award. There is no monetary award, but the recipient's name is added to the wall plaque each year.

During the establishment of the BSE–Mechatronics Concentration, it was decided that no new courses would be created at that time. Instead, current program offerings from mechanical engineering, electrical and computer engineering, and material science, etc. would be organized into a curriculum fitting the mechatronics model. This model has served well, but it is thought that it is perhaps time to reevaluate the current curriculum given data from similar, yet not identical programs, as well as anecdotal data from alumni and industry management.

Lastly, the current faculty and staff of the Two-Plus-Two and BSE programs physically located at UNC Asheville are:

UNC Asheville-Based NC State Staff

Dr. Stephen Walsh, PE Director
Cheryl Alderman, Associate Director
David Erb, Lecturer
Jeremy Brown, Technical Assistant

UNC Asheville Faculty/Staff

Dr. Rebecca Bruce, Associate Director
Diane Morgan, Program Assistant
Cliff Hedrick, Master Control Operator

Peer Assessment

Bucknell University – Dr. Steven Shooter Mechanical Engineering, Dr. Charles Kim Mechanical Engineering, Dr. Maurice Aburdene Electrical Engineering, Dr. Michael Thompson Electrical Engineering, Dr. Joseph Tranquillo Biomedical Engineering.

Dr. Shooter is the driving force behind the mechatronics program at Bucknell University. His expertise spans information management in product design and development on to design of mechatronic systems, which includes automation, animatronics, and robotics.

The Bucknell team states that *Mechatronics is a multi-discipline technical area defined as the synergistic integration of mechanical engineering with electronic and intelligent computer control in the design and manufacture of industrial products and processes*. The Bucknell team members come from mechanical engineering, electrical engineering, and biomedical engineering backgrounds. They have developed a cross-disciplinary course titled *Introduction to Mechatronics* that is cross-listed in both mechanical and electrical engineering. The course is team oriented with a design-based curriculum. Topics covered include automation systems integration, programmable controllers, microcontroller programming and interfacing, actuators and drive systems, and sensor technology.

The overall thrust was toward a course focusing on system level integration skills and shifting their program from so many "cookie-cutter" laboratories to more open-ended design based experiences that pushed critical thinking skills. They have/are reducing the number of core courses in the curriculum and focusing on improving the quality and number of design experiences for students with, again, emphasis on system level integration and decomposition.

The Bucknell faculty has found that students who have previously taken the Mechatronics course do a superior job in their senior capstone design project course.

The Bucknell team also offers an innovative sidebar course in *Product Archeology*– students dissect, research, and reverse engineer older mechanical/mechatronics systems. They also received a three-year KERN grant to develop a series of modules around technology entrepreneurship and new product development.

While mechatronics plays an important role in the Bucknell curriculum, it is a single course and not viewed as a concentration or minor.

California State University Chico – Dr. Ramesh Varahamurti Mechatronic Engineering.

California State University Chico has the oldest ABET accredited mechatronics program in the country housed in their Department of Mechanical and Mechatronics Engineering. The program had its genesis in the Honor University program in California State University Chico and had its official start in 1998 with 10 students and has grown to over 300 in 2014 graduating approximately 30 Mechatronics majors per year. The program was started, and is still run under the direction of Dr. Ramesh Varahamurti and it has strong ties with the Department of Electrical Engineering and Computer Engineering (EECE) and the Department of Computer Science.

The Mechatronics major consists of 128 credits; however, they recommend an additional four to five courses to the students. (They have a significant number of students minor in Physics and Mathematics.)

Dr. Varahamurti commented that he found the mindset of the mechatronics engineering student to be quite different from the traditional mechanical engineering, electrical engineering, and computer engineering students. Specifically, he has found them over the years to be extremely curious and very hands-on engaged.

Their program has a significant design component across the curriculum with over nine courses that include a design experience. In addition, the students are exposed to a rigorous software sequence including programming and algorithm design, logic design, and embedded systems development including real-time operating systems with embedded controllers. (The Departments of Computer Science and EECE teach these courses.) During spring semester junior year, the students participate in two significant design-driven courses: Digital Systems Design and Mechanical Engineering Design. EECE teaches the former and Mechanical Engineering teaches latter. These are heavily component design-driven and require both a paper and product realization.

In addition, students take Electronics-I, which is offered by EECE. This introductory course does not delve deeply into semiconductor physics, but introduces students to discrete components and systems they will encounter while designing and debugging mechatronics systems. Dr. Varahamurti mentioned they previously had a more advanced electronics course, which included more semiconductor physics. However, based on alumni and industry feedback, and the mandate to reduce the overall number of credit hours for the major, they decided to remove it. They also reduced their two-semester sequence in thermodynamics to a one-semester course and made fluid dynamics an option.

In their current core curriculum, five courses are taught by Mechanical Engineering, six by EECE, one by Computer Science, six by Mechatronics, two by Civil Engineering, and then the usual sequence of mathematics, chemistry, physics, and the humanities. An interesting component of the student design experience comes in the form of working with faculty on industry projects. Typically, the department does 15 to 17 projects per year with four to five students per project and one or more faculty. The industry sponsor pays a $5,000 stipend plus the physical production of the product or prototype.

Lastly, this curriculum resembles ours with the exception of their emphasis on the design experience for the students.

Colorado State University Fort Collins – Dr. David Alciatore, PE Mechanical Engineering.

Under the direction of Dr. David Alciatore, the Department of Mechanical Engineering took the unique approach of developing an evolutionary sequence to create a mechanical engineering curriculum that was mechatronics-based. They felt this approach would be more manageable as they sought to restructure their traditional curriculum with a mechatronics theme. Of note is that Dr. Alciatore has written a widely used book *Introduction to Mechatronics and Measure Systems*, which is used in our ECE 456 course. Mechatronics, in his opinion, is an extremely hands-on discipline with a significant design component in pedagogical approach.

Their intent was to create *a curriculum with contemporary emphasis, enhanced content, and improved sequencing and coupling of traditional topics including modeling and analysis, computing, electrical circuits and machines, measurements and instrumentation, control theory, and design* with design and computation playing a leading directional role.

It was thought that mechatronics would provide a natural focus for this endeavor by allowing improved opportunities to connect and use new and existing design experiences across the curriculum. Their proposal consisted of four evolutionary steps. It was felt that this would allow more manageable change in an incremental format thereby providing ease of coordination with faculty and laboratory facilities. As you might imagine, their curriculum is extremely hands-on with 24/7 access to all laboratories–there is a formal certification process plus appropriate safety measures. As such, they incorporate significant amounts of CAD experience early on and begin design in the freshman year culminating in a two-semester, 8-credit, senior design experience.

Like many schools, they were mandated to reduce the number of credits required for degree. In their case, they took a 134-credit curriculum and reduced it to 120 while simultaneously improving the overall student experience. In collaboration with their Industrial Advisory Board, the department uses senior design as the bellwether for the curriculum searching for weaknesses. To date, the surveyed employers have been more than pleased with their new graduates.

While they do collaborate with electrical engineering and computer science, the major thrust of instruction in mechatronics is by mechanical engineering faculty.

Mechatronics has played an important role reshaping the overall mechanical engineering curriculum at Colorado State University Fort Collins by providing an underlying theme. However, students receive no formal recognition such as a certificate, concentration, or minor in the field. While our program differs in many ways, their process and accomplishments provides new and innovative ideas to improve ours.

Georgia Institute of Technology – Dr. Amit Jariwala, Mechanical Engineering.

In March of this year, I attended the NCIIA Open Conference and met Dr. Craig Forest from the Georgia Institute of Technology. Dr. Forest is in the Mechanical Engineering Department and he gave a talk on the program he spearheaded called the Georgia Tech Innovation Studio. The program boasts several unique operating procedures. Dr. Forest invited me to visit and he introduced me to Dr. Jariwala who is the new director of the Innovation Studio.

The Innovation Studio is an amazing university-wide program initiated by the department of mechanical engineering and there are many things they do that we might consider emulating, but that is the subject of another report. When I was visiting, I found out that they have a long-standing tradition in mechatronics engineering and have developed three courses and built a substantial instructional laboratory for mechatronics, which I toured.

The three courses are ME 4405: Fundamentals of Mechatronics, ME 6405: Introduction to Mechatronics, and ME 6408: Advanced Mechatronics (graduate).

For ME 4405 and 6405, the course format consists of lectures, individual laboratory exercises, group laboratory assignments, and a final group project. The laboratory assignments include reverse engineering products, computer interfacing, DC motor control, data acquisition and sensors, and require a presentation and report. The final group project is substantial and is team-driven with instructor guidance. It, too, requires an in class presentation/demonstration and report.

ME 4405 and 6405 are prerequisites for ME 6408: Advanced Mechatronics. The course focuses on team-based projects where they must design and build intelligent machine products. The format of the course is both lecture and project. The project is substantial and done throughout the semester. Lectures include both theory and application in areas such as sensors and transducers, actuators, fluid power, power rectifiers, motion control and modeling of mechatronic systems with several guest lecturers.

There were some impressive student projects ranging from an automated guitar player to a semi-automated shift system for GT motorsports, and a cash dispenser to a two-dimensional laser imaging system.

The major thrust of instruction in mechatronics is by mechanical engineering faculty. The course sequence appears to be quite popular with the students, but it does not constitute a concentration or minor in their college. We are trying to accomplish something more in the long run with our students; nonetheless, their hands-on courses provide good examples of what can be accomplished.

University of Pennsylvania – Dr. Tom Cassel, Practice Professor of Mechanical Engineering and Applied Mechanics (MEAM), Sarah Rottenberg, Integrated Product Design, Dr. Jonathan Fiene, Senior Lecturer MEAM.

The University of Pennsylvania Department of Mechanical Engineering and Applied Mechanics has a unique relationship between engineering entrepreneurship, product design, and mechatronics. Dr. Cassel founded the engineering entrepreneurship program in 1999 after a successful career as both an engineer and entrepreneur. Sara Rottenberg is the Associate Director of the Integrated Product Design Program at the University of Pennsylvania, a Master's Program bringing together design, business and engineering, and a Lecturer in the School of Design. Dr. Fiene is a Senior Lecturer in MEAM, Director of Laboratory Programs and he is responsible for their mechatronics courses MEAM 410/510. Together, these three have heavily influenced the curriculum trajectory toward design-based experiential learning.

Mechatronics has been in MEAM for nearly ten years. Dr. Fiene has been responsible for growing and running the sequence for more than seven years relying heavily on his work at Stanford. The course is an elective and is lab/practice based. The laboratory is open 24/7 with 30 stations, but the students can do work at other locations. They also borrow laboratory time and equipment from other areas including CAD software, eight MakerBots, two high-end 3D printers, and four laser cutters that are all highly utilized.

The course is about design and synthesis and has grown to a point where there is one full-time laboratory instructor and between eight to ten class alumni who are hired as lab assistants and graders. The course is very time consuming with a three-hour lecture and a laboratory experience taking between six and twenty hours per week. Students typically take this class before their senior capstone design course. Faculty have seen a marked improvement in the senior capstone design of these students. In addition, alumni talk about the exposure they get to potential employers and how these employers are impressed with their system-level perspective and their prototyping ability.

The course boasts students from literally all the major engineering disciplines. The bulk of the students are juniors, seniors, and a fair number of graduate students. The current enrollment is nearing one hundred, but the course is still a stand-alone one with no specific concentration or minor, and it is solely taught by MEAM faculty in collaboration with Design faculty. As such, it provides us with another example of design-based instruction we may want to consider in our own curriculum.

Southern Polytechnic State University – Dr. Chan Ham Electrical & Mechatronic Engineering.

The ABET accredited Mechatronics program is very multidisciplinary with collaboration from mechanical engineering, electrical engineering, computer science, and mechatronic engineering. They have a current enrollment of approximately 250 students. Their graduation rate is quite high and they boast a 95% employment rate at graduation. The students are sought after due to their system-level perspective and they typically move into technical lead positions in a much shorter span of time compared to those in other disciplines.

Their focus on engineering education comes from the fact today's technology is not tomorrow's and they must stress with their students the concept of learning to learn. The curriculum is 128-credit hours with 18 hours of mechanical engineering courses, 20 hours of electrical engineering course, 4 hours of computer science courses, 17 hours of mechatronics engineering course, and the remainder comprised of core science and humanities. Note that the curriculum offers no courses in thermodynamics, solid mechanics, or dynamics of machines.

The third year is where formal mechatronics education begins. It is a hands-on curriculum and they make extensive use of CAD/CAM programs, LabView and PLC programming exercises. The senior capstone design project incorporates structural mechanical design, sensors and data acquisition, actuators and hydraulics, and computer systems integration. They have substantial industry backing for the program.

In the future, the program plans a special course in Mecha-Electronics theoretically positioned between their circuit theory course and a traditional microelectronics course. It will be more systems-level with a mixture of lecture and laboratory–it is not intended to be a vocational class, but rather one with an aim toward theory and application.

Graduates often choose to pursue both general MSE and more specialized masters in mechanical, electrical and computer engineering. For the specialized masters, students must take additional coursework in order to pursue them; however, the school will begin offering their own Masters in Mechatronics next year.

There are numerous similarities to our program–courses, collaborations, etc. Yet, ours is richer in theory and theirs in hands-on design experience within the classes.

Self Assessment

NC State University / UNC Asheville – Faculty from Mechanical Engineering, Electrical and Computer Engineering and Materials Science.

The BSE–Mechatronics Concentration (JEM) offered at UNC Asheville is a joint offering of NC State University College of Engineering and UNC Asheville. It is an amalgam of courses taught by faculty at UNC Asheville and by faculty at NC State University through online distance education. The amount of courses taught by each institution is roughly a 50/50 split. There are approximately ten courses (32 hours) taught by Electrical and Computer Engineering, nine courses (27 hours) by Mechanical Engineering, and one course (3 hours) by Materials Science. UNC Asheville faculty teaches the remainder of the core sciences, mathematics, and humanities. Currently, there are 124 credit hours required for the degree.

The curriculum has a 2-credit *Introduction to Mechatronics Lab* in spring of freshman year, a 1-credit *Advanced Mechatronics Design Lab* in fall of junior year and a 4-credit *Senior Capstone Design* sequence split 3-credit/1-credit over the fall/spring semesters of senior year.

Both the Mechanical Engineering and the Electrical and Computer Engineering Departments have delivered rich sequences of engineering courses in their respective disciplines. Anecdotal reports from industry employers support a strong demand and appreciation for the quality of students coming from this program.

Recommendations

Of the six institutions visited, California State University Chico and Southern Polytechnic State are the most closely aligned with our joint BSE-Mechatronics Concentration. The other four institutions offered examples of best practices in specialized mechatronics courses designed to introduce students to the discipline and how one institution used mechatronics to realign their mechanical engineering curriculum around design-based experiences for their students.

California State University Chico and Southern Polytechnic State graduate students with mechatronic engineering degrees. By contrast, our program graduates students with a Bachelor of Science in Engineering with a *concentration* in mechatronics. The point for reflection is how extensive should the concentration of mechatronics be and how can it best be delivered to the students. Should the curriculum be completely reworked? Would more minor revisions make more sense? How could the four-year design experience be enhanced?

My recommendation is that we consider small, yet important, revisions to the curriculum and these be done to enhance the design-based experience for the students. Specifically, with the exception of adding a CAD class in freshman year (JEM 123), the first two years of study would remain unchanged; the program would be as follows:

Freshman Year

Fall

MATH	191 Calculus I	4
LANG	120 Foundations of Academic Writing	4
CHEM	132 General Chemistry	3
CHEM	111 General Chemistry Lab	1
E	101 Intro to Engr & Problem Solving	1
JEM	123 Intro to CAD for Engineers	1
[DEPT]	178 LAC: First Year Colloquium	3
		17

Spring

MATH	192 Calculus II	4
PHYS	221 Physics I	4
ECE	109 Intro to Computer Systems	3
JEM	180 Intro to Mechatronics Lab	2
HUM	124 The Ancient World	4
		17

Sophomore Year

Fall

MATH	291 Calculus III	4
PHYS	222 Physics II	4
ECE	200 Intro to Signals, Circuits & Systems	4

ECE	209 Computer Systems Programming	3
MAE	206 Engineering Statics	3
		18

Spring

ECE	211 Electric Circuits	4
ECE	212 Fundamentals of Logic Design	3
ECE	220 Analytical Foundations of ECE	3
MAE	208 Engineering Dynamics	3
ECON	102 Microeconomics	3
		16

Junior Year

Fall

ECE	306 Introduction to Embedded Systems	3
MAE	301 Engineering Thermodynamics I	3
MAE	315 Dynamics of Machines	3
EGM	360 Advanced Mechatronics Design Lab	2
ARTS	310 Arts and Ideas	3
		14

Spring

ECE	310 Design of Complex Digital Systems	3
MAE	314 Solid Mechanics	3
MAE	435 Principles of Automatic Control	3
ECE	456 Mechatronics	3
HUM	214 Rise of European Civilization	4
		16

Senior Year

Fall

EGM	484 Senior Design Mechatronic Engr I	3
MAE	310 Heat Transfer Fundamentals	3
MAE	308 Fluid Dynamics	3
	Approved Advised Elective	3[c]
HUM	324 The Modern World	4
		16

Spring

EGM	485 Senior Design Mechatronic Engr II	3
STAT	225 Into to Calculus-based Statistics	4
MAE	316 Strength of Mechanical Components	3
LA	478 Liberal Studies Senior Colloquium	4[d]
		14

[c] ECE 455, Computer Control of Robots; EGM 492 Mechatronics Systems Modeling; MSE 201 Structure & Properties of Engineering Materials, or Advised Elective approved by Director.

[d] or HUM 414

In fall semester junior year, ECE 306, Introduction to Embedded Systems would replace ECE 301, Linear Systems. The reasoning is twofold: First, students need exposure to embedded systems and real-time operating environments, which they currently do not receive; second, none of the programs visited offered a course in Linear Systems and this material can be sufficiently covered in MAE 435, Principles of Automatic Control and the proposed senior year elective EGM 492 Mechatronics Systems Modeling. In addition, the credit hours for EGM360 Advanced Mechatronics Design Lab would increase from 1-credit to 2-credits. This course serves as the foundation for our IEEE Robotics Competition and it meets twice per week for 1h40m in a lecture/lab style combination. This, combined with the additional out of class assignments, makes a course workload that is substantially more than 1-credit.

In spring semester junior year, ECE 456, Mechatronics, would be added as a required course. This would change the semester credit hours from 13 to 16. Previously, ECE 456 was listed as an advised elective in the senior year, but placing it here will integrate a design experience into the second semester of the junior year. It is hoped that, as seen in the other institutions visited, we will see an improvement in the quality of the projects in senior capstone design the following year.

In senior year, MAE 308, Fluid Dynamics would be added as a required course to fall semester, and ECE 484/5 would be modified to a 6-credit hour two-semester sequence. The intent is to mimic, where appropriate, the current ECE two-semester sequence. This would change the fall semester credit hours from 13 to 16 and the spring semester credit hours from 15 to 14. ECE 455, Computer Control of Robots and a new proposed course, EGM 492, Mechatronics Systems Modeling, and MSE 201 Structure & Properties of Engineering Materials would be the three approved advised electives. EGM 492 will be modeled after a course taught by a former adjunct in Asheville. It will introduce students to the development of mathematical models of engineering systems, including electric motors, and the necessary strategy and algorithms required to satisfy the specifications of a controlled process. Several employers have commented this course (a system modeling course) helped to distinguish the student during the interview process–the employers were impressed with the course project and course scope–and their performance on the job. In addition, numerous students have stated the value of the course on their job.

These proposed changes would move the required credit hours from 124 to 128.

Conclusion

The success of both our 2+2 and Mechatronics programs hinge on our ability to build a strong infrastructure and cultural base surrounding the BSE–Mechatronics Concentration. The more solid the foundation here, the better prepared the 2+2 students will be for their transition to NC State or sister institutions to complete their studies in the discipline of their choice.

With our structural position as a combination NC State College of Engineering and UNC Asheville, we are truly a ‘House United’ and the students benefit from the unique strengths and resources of the two institutions.

On many fronts, the BSE–Mechatronics Concentration compares more than favorably to other programs. We offer a richer and more comprehensive sequence of engineering coursework than any of the programs visited. In addition, due to the joint collaboration with UNC Asheville, our students are exposed to a broad spectrum of the arts and humanities. Anecdotal reports from industry employers support a strong demand and appreciation for the quality of students coming from our program. Our students are sought after by industry with 100% employment for our graduates over the past four years and they do well in their careers. While we have a strong program, our principle areas for potential improvement surround added competencies in embedded systems and real-time operating systems, and in design-based experiences. With some minor curricular changes we can make a strong program even better and improve the preparation of our mechatronics students for the workforce of tomorrow.

References and Notes

Jackson, N. & Lund, H. (eds.) (2000) Benchmarking for higher education, Society for Research into Higher Education & Open University Press, UK.

Action Plan

The Mechatronics Course and Curriculum Committee met on October 3rd and unanimously passed the recommendations set forth in this proposal. The next steps include creating the appropriate documentation to be presented to the NC State College of Engineering’s Course and Curriculum Committee in November. Once, it is hoped, that it passes this committee, then it moves on to the University Course and Curriculum Committee for final approval.

Appendix

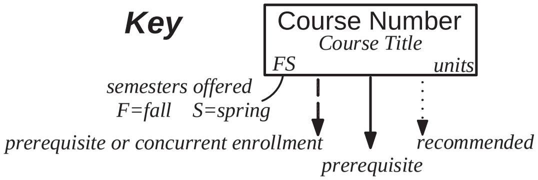
Mechatronic Engineering

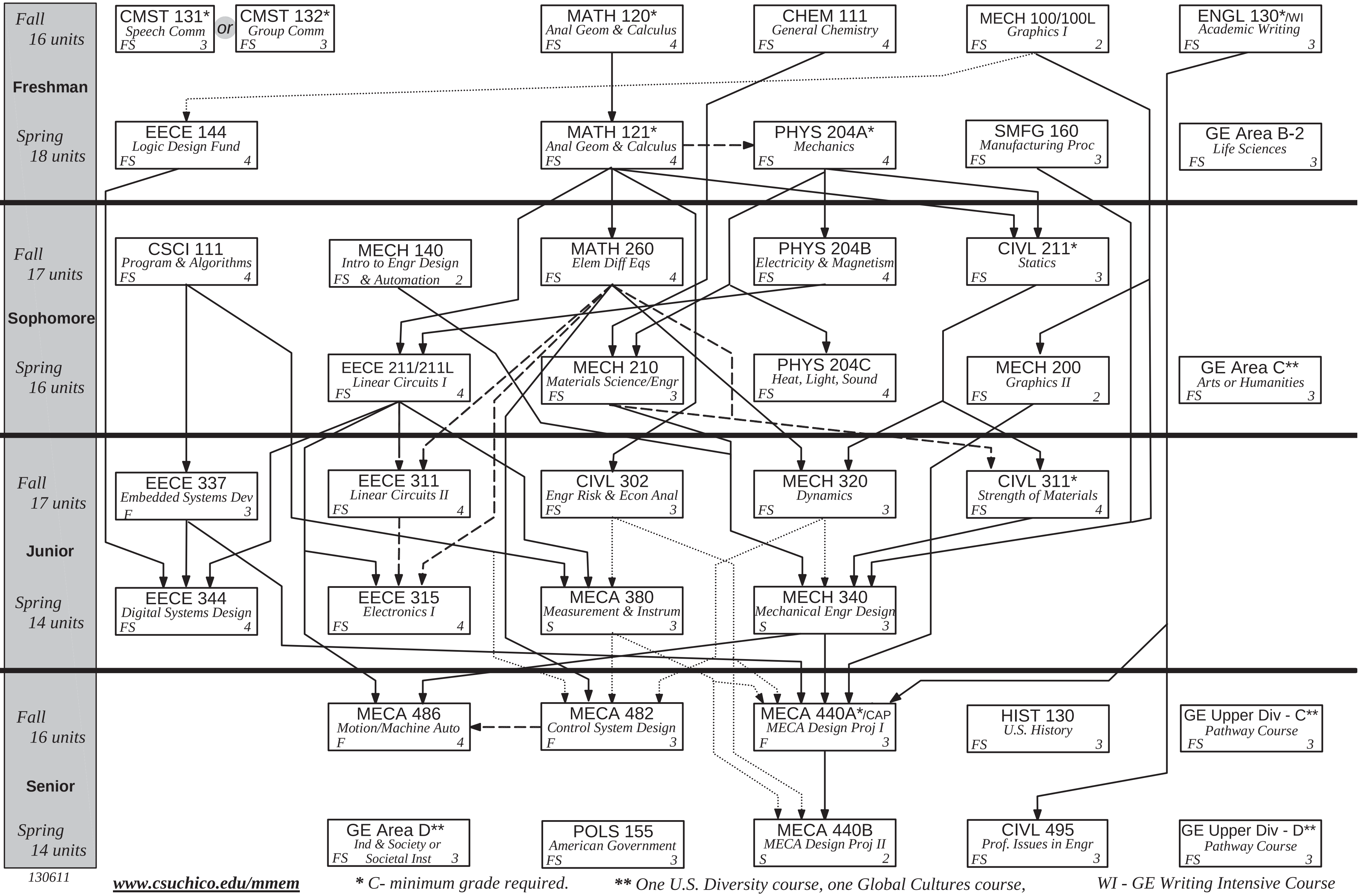
Major Academic Plan

Flowchart Format

University Catalog 2013-2014

Key





www.csuchico.edu/mmem

* C- minimum grade required.

** One U.S. Diversity course, one Global Cultures course, and two Writing Intensive (WI) courses are required.

WI - GE Writing Intensive Course
CAP - GE Capstone/WI Course

SPSU Southern Polytechnic State University

MECHATRONICS ENGINEERING 2014 rev.1

Freshman	**Fall**	**CHEM 1211** **and** CHEM 1211L Chemistry I 3-3-4 Credits MATH 1111 Pre-req	**EDG 1211** Engineering Graphics I 3-0-3 Credits	**MATH 2253** Calculus I 4-0-4 Credits MATH 1113 Pre-req	**MTRE 1000** Introduction to Mechatronics Engineering 2-0-2 Credits	**ENGL 1101** Composition I 3-0-3 Credits	= 16 Credits
	Spring	**PHYS 2211** **and** PHYS 2211L Physics I 3-3-4 Credits MATH 2254	**MATH 2254** Calculus II 4-0-4 Credits MATH 2253 Pre-req	**CSE 1301E** Engineering Programming 3-3-4 Credits MATH 1113 Pre-req	**ENGL 1102** Composition II 3-0-3 Credits ENGL 1101 Pre-req	**SPSU 1001** Hitchhikers Guide to SPSU 1-0-1 Credits	= 16 Credits
Sophomore	**Fall**	**MTRE 2610** Engineering Algorithms & Visualization 3-0-3 Credits MATH 2253, CSE 1301E	**MATH 2306** Differential Equations 3-0-3 Credits MATH 2254 Pre-req	**EE 2301** Circuit Analysis I 3-3-4 Credits PHYS 2211 Pre-req	**PHYS 2212** **and** PHYS 2212L Physics II 3-3-4 Credits MATH 2254, PHYS 2211	**ENGR 2214** Statics 3-0-3 Credits PHYS 2211 Pre-req	= 17 Credits
	Spring	**ENGR 3122** Dynamics 3-0-3 Credits ENGR 2214 Pre-req	**COMM 2400** Public Speaking 2-0-2 Credits	**MATH 3312** Linear Algebra 4-0-4 Credits MATH 2254 Pre-req	**EE 3401** Engineering Electronics 3-3-4 Credits EE 2301 Pre-req	**MATH XXXX** *Mathematics Elective 3-0-3 Credits	= 16 Credits
Junior	**Fall**	**EE 2501** Digital Logic Design 3-3-4 Credits EE 2301 Pre-req	**ENGR 3131/32** Strength of Materials / Lab 3-0-3 / 0-3-1 MATH 2254, ENGR 2214	**MATH 2255** Calculus III 4-0-4 Credits MATH 2254 Pre-req	**STS 2400** Science, Tech, & Society 2-0-2 Credits ENGL 1101 Pre-req	**CORE C1** Literature 3-0-3 Credits ENGL 1102 Pre-req	= 17 Credits
	Spring	**ENGR 3343** Fluid Mechanics 3-0-3 Credits ENGR 2214, MATH 2254	**MTRE 3710** Mechatronics Engineering Fundamentals 3-3-4 Credits MATH 3312, CSE 1301	**ECON 2107** Engineering Economics 3-0-3 Credits MATH 2253 Pre-req	**EE 4201** Control Systems 3-3-4 Credits MATH 2306, EE 2301, ENGR 2214		= 14 Credits
Senior	**Fall**	**CORE E1** US History or Political Science 3-0-3 Credits	**MTRE 4000** Advanced Controls 3-0-3 Credits EE 4201 Pre-req	**XXXX** **Technical Elective 3-3-4 Credits	**XXXX** **Technical Elective 3-0-3 Credits	MTRE 4100 Instruments And Controls 3-3-4 Credits EE 2501, EE 3401, MATH 2306	= 17 Credits
	Spring	**CORE E2** World Civilization 3-0-3 Credits	**MTRE 4200** Robotic Anal. & Syn. 3-3-4 Cr. MTRE 3710, EE 4201 or ME 3501, & MATH 2255	**CORE C2** Arts 3-0-3 Credits ENGL 1101 Pre-req	**MTRE 4400** Mechatronics System Design 2-6-4 Credits MTRE 4000, MTRE 4100, ECON 2107	**CORE E4** Cultures and Societies 3-0-3 Credits	= 14 Credits

*Mathematics Electives: MATH 2260, 2335, 2345, 3268 or equivalent

**Technical Elective: EE 3XXX/4XXX, ME 3XXX/4XXX, ENGR 3XXX/4XXX, SYE 3501, SYE 3502, SYE 4501, CS 4533, or equivalent

PLAN OF STUDY
JOINT NC STATE – UNC ASHEVILLE
BACHELOR OF SCIENCE IN ENGINEERING CURRICULUM
MECHATRONICS CONCENTRATION (JEM148)

Plan of Study
Joint NC State – UNC Asheville
Bachelor of Science in Engineering Curriculum
Mechatronics Concentration (JEM148)

Effective August 1, 2014

Freshman Year

FALL SEMESTER				SPRING SEMESTER			
MATH	191	Calculus I	4#	MATH	192	Calculus II	4#
LANG	120	Fndns of Academic Writing	4$	PHYS	221	Physics I	4#
CHEM	132	General Chemistry	3#	*ECE*	*109*	*Intro to Computer Systems $*	3$
CHEM	111	General Chemistry Lab	1#	*EGM*	*180*	*Intro to Mechatronics Lab*	*2*
E	*101*	*Intro to Engr & Prob Solving*	*1*	HUM	124	The Ancient World	4
[DEPT]	178	LAC: First Year Colloq	3[a]				17
			16				

Sophomore Year

FALL SEMESTER				SPRING SEMESTER			
MATH	291	Calculus III	4	*ECE*	*211*	*Electric Circuits*	*4$*
PHYS	222	Physics II	4	*ECE*	*212*	*Fundamentals of Logic Design*	*3$*
ECE	*200*	*Intro to Signals, Circ & Systems*	*4$*	*ECE*	*220*	*Analy Foundations of ECE*	*3$*
ECE	*209*	*Computer System Programm'g*	*3$*	*MAE*	*208*	*Engineering Dynamics*	*3$*
MAE	*206*	*Engineering Statics*	*3$*	ECON	102	Microeconomics	3
			18				16

Junior Year

FALL SEMESTER				SPRING SEMESTER			
ECE	*301*	*Linear Systems*	*3*	*ECE*	*310*	*Design of Complex Digital Sys*	*3*
MAE	*301*	*Engr Thermodynamics I*	*3$*	*MAE*	*314*	*Solid Mechanics*	*3$*
MAE	*315*	*Dynamics of Machines*	*3*	*MAE*	*435*	*Principles of Automatic Control*	*3*
MSE	*201*	*Struc & Prop of Engr Matls*	3	HUM	214	Rise of European Civilization	4
EGM	*360*	*Adv Mechatronics Design Lab*	*1*				13
ARTS	310	Arts and Ideas	3[b]				
			16				

Senior Year

FALL SEMESTER				SPRING SEMESTER			
EGM	*484*	*Senior Design Mechatronic Engr I*	*3*	*ECE*	*455*	*Computer Control of Robots*	*3*
MAE	*310*	*Heat Transfer Fundamentals*	*3*	*EGM*	*485*	*Senior Design Mechatronic Engr II*	*1*
HUM	324	The Modern World	*4*	*MAE*	*316*	*Strength of Mech Components*	*3*
		Approved Advised Elective	*3*[c]	STAT	225	Intro to Calc-based Statistics	*4*
			13	LA	478	Liberal Studies Senior Colloq	*4*[d]
							15

Credit Hours Required: 124

Italics indicates NCSU Engineering course.

[a] LAC 178 is not required for transfer students with 25 credits or more. For such students, Minimum Credit Hours Required is 121.

[b] Preferably any course which satisfies the ARTS requirement and is designated as DI, Diversity Intensive.

[c] MAE 308, Fluid Dynamics; ECE 456, Mechatronics or Advised Elective approved by Director.

[d] or HUM 414

Students must satisfy UNC Asheville foreign language proficiency requirement via testing or credit courses.

\# Grade of C or better required.

$ Grade of C- or better required.

5/28/14

INTERDISCIPLINARY COLLABORATIVE LEARNING IN MECHATRONICS AT BUCKNELL UNIVERSITY

Interdisciplinary Collaborative Learning in Mechatronics at Bucknell University

STEVEN SHOOTER
Department of Mechanical Engineering
Bucknell University

MARK MCNEILL
Department of Electrical Engineering
Catholic University

ABSTRACT

Examination of the "cone of learning" shows an increase in retention when students are actively engaged in the learning process. Mechatronics is loosely defined as the application of mechanical engineering, electrical engineering, and computer intelligence to the design of products or systems. By its nature, mechatronics is an activity-oriented course. The course content also provides an opportunity to employ interdisciplinary collaborative learning with active learning techniques. The mechatronics course at Bucknell consists of mechanical and electrical engineering students at the senior and graduate levels. The students engage in a variety of activities in teams comprised of members from each of these groups. In addition to team laboratory exercises and homework assignments, the students work in interdisciplinary groups to process their efforts. That is, they engage in meaningful discussion among themselves concerning their activities and the implications of the various results. The students also act as teachers by preparing lectures and exercises on topics from their discipline to the students in the cross discipline. Specifically, the electrical engineers teach the mechanical engineers microcontrollers, and the mechanical engineers teach the electrical engineers mechanisms. This paper describes the learning techniques employed in this course, as well as the interpretation of the results from the students. It also discusses the relationship of the course outcomes to Criterion 3 of the engineering accreditation criteria promulgated by the Engineering Accreditation Commission of the Accreditation Board for Engineering and Technology (EAC/ABET).

I. INTRODUCTION

It is clear from a review of recent literature on mechatronics [1–3] that recognizing the interdisciplinary nature of modern technical systems is essential. Engineering curricula internationally are recognizing the need to develop engineers proficient across traditional engineering fields [4–6]. While each school has chosen to emphasize particular aspects of mechatronics in their course, the focus remains on interdisciplinary topics. At Bucknell we have developed the mechatronics course to exploit the strengths found in its interdisciplinary and applied nature.

In his "Cone of Learning", Dale [7] suggests that people learn and retain 20% of what they hear, 30% of what they see, 50% of what they see and hear, 70% of what they say, 90% of what they experience directly or practice doing. While there are logistical advantages to the standard lecture format, it is advantageous to use active learning techniques whenever possible. Because of the applied nature of mechatronics, there are many opportunities to engage students in active learning through laboratory and design exercises. It is then a relatively easy leap for students to accept other practices of active and collaborative learning in the classroom setting.

In our syllabus we describe mechatronics as a multi-discipline technical area comprised of the synergistic integration of mechanical engineering with electronic and intelligent computer control in the design and manufacture of industrial products and processes. Given that the technical area is interdisciplinary, we saw a benefit to including students from mechanical and electrical engineering. The elective course was cross-listed in each department. The intent was to draw on the strengths of the students in their disciplines to advance the learning of the entire class. The class provided the opportunity for students to reinforce their discipline-specific knowledge and integrate it with new knowledge and applications.

We also focused on the applied nature of mechatronics. This design-directed course covered topics such as actuators and drive systems, sensors, programmable controllers, microcontroller programming and interfacing, and automation systems integration. Rather than start with theory, we focused on how to specify, integrate, and use mechatronic elements in a system. Theory was provided as supporting information. A larger emphasis was placed on discerning the advantages and disadvantages among alternative elements and appropriate selection for a desired application. Students explored alternative approaches through a variety of exercises in the classroom, the laboratory and the design setting.

This paper describes the collaborative and active learning techniques employed in this course. It begins with a general overview of collaborative and active learning theory. The next section describes the activities used in the course to employ those theories. This is followed by a discussion of the relationship of this course to Criterion 3 of the EAC/ABET and techniques for assessment. Finally, reflections on the course are provided.

II. COLLABORATIVE AND ACTIVE LEARNING

Lecturing to a classroom of students is probably the most common form of "information transfer" used to teach at the university level. This method places undo pressure on both the professors administering the lectures as well as the students forced to identify and process important concepts in the presentations. To the contrary, collaborative learning removes the professor as the so-called expert on the course material and empowers students with control of their own understanding of both basic and advanced concepts. Implicit with collaborative learning in addition to higher retention is the students' ability to achieve a deeper understanding of the subtle concepts and procedures.

One of the main concepts involved in collaborative learning is the emphasis of having students work together to get a job done. This is best realized by five basic tenets [8]:

- *Positive interdependence* exists when students believe that they are linked with others in a way that one cannot succeed unless the other members of the group succeed.
- *Face-to-face promotive Interaction* exists among student when students orally explain to each other how to solve problem, discuss with each other the nature of the concepts and strategies being learned, teach their knowledge to classmates, and explain to each other the connections between present and past learning.
- *Individual accountability* requires the professor to ensure that the performance of each individual student is assessed and the result give back to the group and individual.
- *Collaborative skills* are those students must have and use the needed leadership, decision-making, trust-building, communication, and conflict-management skills.
- *Group processing* involves a group discussion of how well they are achieving their goals and how well they are maintaining effective working relationships among members.

III. COURSE STRUCTURE

We designed our mechatronics course to place students in the best possible position to both actively learn the course material as well to work collaboratively to achieve in-depth understanding of complex concepts. This includes everything from studying and processing complex data sheets to developing team-oriented lectures in a multi-disciplinary environment. According to Smith [9], collaborative learning may be incorporated into courses through the use of: 1) informal learning groups; 2) formal learning groups; and 3) collaborative base groups. Informal learning groups are often less structured and thus last for a short term. Formal learning groups are more structured and normally last until a task is done. They normally last from one class period to a few weeks. The method we employed implements the collaborative base group idea where groups are carefully constructed and stay together for a majority of the semester. In our case, we assigned interdisciplinary groups of four to five students that stayed together up to the final project phase of the course. For the design projects, we allowed students to establish their own groups based on established guidelines. We now discuss the four cornerstones of our approach: group processing, group homework assignments, interdisciplinary laboratory groups, and student lectures.

A. Group Processing

We approached group processing with both in-class and out-of-class assignments. Students were asked to find information jointly as a group and then compare and contrast the advantages and disadvantages of competing components, systems, and processes. For example, one assignment required each student to locate a data sheet for a particular sensor and explain each of its specification terms. Students then gathered into groups of four to review their work. Processing took place by having students compare and contrast the characteristics of the sensors while recognizing that the primary function of a sensor is to receive input from the environment. The students submitted individual assignments that deciphered their particular sensor's data sheet and a group report that compared and contrasted the sensors presented by each group member. After small group discussions, the class as a whole discussed the numerous sensors found by all groups during the assignment to gain a better appreciation for design options in the future. One point that was discussed at length was how mechanical engineering students were often surprised by the amount of electrical circuitry needed to interface particular sensors to computers. In fact, much of the confusion with sensors was not in their ability to sense the outside environment, but rather in their ability to be interfaced to a microcontroller. Group processing allowed students to discuss and resolve issues concerning interfacing sensors to a mechatronic system. An additional benefit with group processing was that the total amount of sensor types covered actually increased. This type of activity allowed students to interpret a larger number of alternative applications of mechatronic components than if they had acted individually.

B. Combined Homework

The five tenets of collaborative learning guided our process for designing and evaluating homework assignments for the course. Specifically, we developed assignments that promoted responsibility by each member of the group. Because this was an interdisciplinary course combined with both electrical and mechanical engineers, the skill sets of the teams typically spanned a wide range. Our task was to design assignments that were co-dependant such that members of the group had to talk with one another. The most popular assignment was to have student use the Web or library to research mechatronic components and sub-systems that are available from manufacturers. We did this for sensors, pneumatic and hydraulic actuation, motors, and mechanisms. A large part of our processing of what the students were able to find was a broad discussion of what components and systems make sense to include in realizable mechatronic systems. All homework had both an individual and group component.

C. Team Laboratory Exercises

Laboratory activities were developed around five broad design-oriented laboratory assignments. We carefully selected laboratories centered around:

1) sensors and transducers,
2) microcontrollers,
3) mechanical actuation systems,
4) digital logic and motor control, and
5) Programmable Logic Controllers

The strategy employed was necessary to maximize the backgrounds of the students in the class while also empowering the students to learn a lot of complex material to a depth sufficient for use in real mechatronic design.

Laboratory groups consisted of the same cooperative-based groups presented in the previous section. One of the points of concern for the mechanical engineering students and us was the heavy emphasis on electronics. This is to be expected due to the cheaper cost of electronic components combined with their increased flexibility and programmability. To present a less electronic picture to the students was not an option we considered. A positive finding through the laboratory portion of the course was the consistent emphasis we placed on both system design and design methodologies.

D. Student Lectures

Because we had the unique opportunity to have a class that was composed of students from two different disciplinary programs, we decided to incorporate student teaching as a viable method for student learning. Two of the topics covered in the class were a review for half of the students. The mechanical engineers had taken a course in mechanisms and the electrical engineers had taken a course in microcontrollers. As noted in the introduction through the cone of learning, the average retention rate of students is 90% when students teach others. Having students teach the lectures helped them reinforce the material they had learned in a previous class. The electrical engineers taught the mechanical engineers about using microcontrollers, and the mechanical engineers taught the electrical engineers about mechanisms. In both cases the students exceeded our expectations and showed us the level at which they can understand and digest complex information.

The electrical engineers introduced the microcontroller through three carefully planned lectures. For this activity, the nine electrical engineers in the course were organized into three groups of three. The first group gave an overview of the microcontroller's architecture and then provided several illustrative demos. This was a hands-on lecture where the mechanical engineers were organized into seven groups where each group was given a Motorola 68HC11 microprocessor to program. During this first lecture, the electrical engineering students lead the class through the proper sequence to establish communication with the microcontroller and to download and run a simple program. The second group presented more difficult programs and prepared a laboratory that incorporated the knowledge gained about sensors to allow students to write simple programs to interface with the outside world. This group even developed a Web page to assists students outside of normal class hours. Lastly, the third group presented higher level constructs such as interrupts and timing. They also presented some programming tips and reviewed some basic principles of developing flowcharts for programs.

The mechanical engineers introduced mechanisms through a series of six 25-minute mini-lectures. The intent of the lectures was to introduce the topics and increase awareness of the possible uses for the mechanisms. The first group taught about the concept of kinematic chains and the use of Grubler's mobility equation to determine degrees of freedom. The second group described the four-bar linkage and slider crank mechanism and provided examples for their configurations and inversions. The third group presented a variety of linkages such as the skotch yoke, quick return, toggle and pantograph, and they discussed locating mechanisms in an encyclopedia. The fourth group taught about different types of couplings such as the universal joint and constant velocity joints. The fifth group introduced cam mechanisms and the different configurations. The sixth group taught about gear trains and the determination of angular velocity ratios. In each case the students exceeded our expectations by including simulations from Working Model and physical demonstrations. The result from this exercise is that the students prepared more vibrant lectures than we could have by ourselves. They also knew which topics they found difficult when they were learning so they emphasized those points. The student response on the exercise was overwhelmingly positive. They acknowledged that teaching the material helped them better understand it. They also indicated an increased appreciation for the effort that goes into quality instruction.

E. Design Projects

The final five weeks of the semester were devoted to the design and implementation of a working mechatronic system. The design experience helps them to integrate their knowledge of mechatronic systems and apply it to a real problem. Students formed their own teams of four students. The only restriction we placed on them in forming the teams is that they had to be interdisciplinary. This differed from our practice the rest of the semester where we assigned the interdisciplinary teams. We wanted to give the students the opportunity to assess individual strengths and form teams on their own.

Students were allowed to select their project from a variety that we had described. We prescribed the project alternatives because we wanted to control the scope based on the short timeframe. We also had a personal interest in seeing some of the projects completed. The projects varied in emphasis on the aspect of mechatronics, but each contained all elements of the course. The projects included: (1) integration and implementation of the Festo automation modules; (2) design and implementation of a snowboard fatigue testing system; (3) design and implementation of a laser light show; (4) design and implementation of a robot caterpillar responsive to its environment; and (5) control of an autonomous robot arm.

Students were required to prepare a complete design report and give a presentation that included the demonstration of their working systems.

IV. RELATION TO EAC/ABET CRITERION 3

The new engineering accreditation criteria are having a positive effect on many engineering programs around the country. The shift in the accreditation philosophy to a system based on the development of the entire student is evident in the EAC/ABET program outcomes for Criterion 3 (a-k) [10]. In developing our mechatronics course, we were concerned with eight specific outcomes:

a) an ability to apply knowledge of mathematics, science, and engineering;
b) an ability to design and conduct experiments, as well as analyze and interpret data;
c) an ability to design a system, component, or process to meet desired needs;
d) an ability to function on multi-disciplinary teams;
e) an ability to identify, formulate, and solve engineering problems;
g) an ability to communicate effectively;
i) a recognition of the need for, and an ability to engage in life-long learning; and
k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

We incorporated the necessary activities to ensure that we met these outcomes. As stated in the previous section, this was done within the confines of active and collaborative learning. Outcome (a) was achieved through the normal use of lectures and homework assignments. In most cases the students understood the technical details of engineering problems very well. Our approach emphasized this understanding by combing outcome (a) with outcomes (e) and (g). For example, the microcontroller laboratory had an open-ended component where students were expected to develop a subsystem to address a particular task. The tasks were assigned to groups in pairs so that group discussions could focus on the creativity and engineering judgement of competing designs. We also enforced this in the group processing assignments and activities. As stated in the introduction, the course was organized to operate as a interdisciplinary course by ensuring that approximately equal amounts of electrical and mechanical students enrolled. Life-long learning was reinforced through the data-sheet-exploration exercises because students had to learn how to find and interpret new information on their own. The ability to use modern engineering tools was built into the course through the use of microprocessor hardware, kinematics modeling software, and PLC environment tools.

The following assessment and evaluation procedures ensured that any student passing this course satisfies all of the learning objectives stated in the syllabus and thereby satisfies the relevant outcomes above. We encouraged working in small groups to solve most problems. During selected class periods, the class was divided into small groups for discussion or to develop solutions to a problem. Written output and class discussion was the expectation. Here we were trying to develop the students' abilities to communicate effectively by explaining rather complex systems and components. The laboratory portion of the course ensured that the students would plan and execute experiments, process and interpret data, and communicate technical concepts. In fact, in-laboratory performance and laboratory reports are the sole basis for evaluation other than homework assignments. Lastly, students worked in interdisciplinary teams to complete the design and implementation of a mechatronic system. The design exercise required them to integrate their knowledge of mechatronic systems and apply it to make a working system.

As evident in the assignments and organization of the course, the outcomes coupled with collaborative teaching techniques enhanced the students' experience in the course. We questioned the students on both their understanding of mechatronics before and after the course and found that they had a much better understanding of the enormity of the field. They enjoyed the opportunity to actively learn and felt that this way of teaching empowered them to learn more than direct lecturing. One draw back expressed by the students was that the course was heavily weighted toward electrical engineering. Unfortunately, this is the nature of the course since electronic controls and sensors are embedded into most mechanical systems. The appreciation of this was evident when the students completed their design projects and had a better understanding of sensors, computers, and mechanical systems that allowed for the careful construction of complex systems.

V. COURSE ASSESSMENT

The competencies of the students were assessed through the performance on the varied exercises throughout the term: homework, laboratory exercises, team teaching, and the design project. Because all of these activities were collaborative, we used several techniques to establish individual evaluations. In some cases students submitted individual written assignments. For example, on the homework assignments where students researched mechatronic components, each student submitted a brief report on his/her selected component, but included a comparison to the other students' components. In the cases where students submitted single group reports, students were required to include a section on the contributions of each group member. For the final design project, each student also submitted a confidential evaluation of each member that was considered in assigning final grades. For that evaluation students rated each group member's performance on a five-point scale (1 = pathetic, 2 = poor, 3 = fair, 4 = good, 5 = excellent) on the following items. The individual:

1. attended and contributed to the group meetings;
2. performed his/her tasks in a timely manner;
3. performed communication tasks in a quality manner;
4. performed technical tasks in a quality manner;
5. demonstrated a willingness to work toward the benefit of the group; and
6. contributed to the overall performance of the team.

We also asked the students to rate their own competencies on the objectives of the course through a questionnaire. The students were asked to rate their perceived level of achievement and understanding of the following objectives on a five-point scale (1 = No ability, 2 = limited ability, 3 = moderate competency, 4 = competent, 5 = expert). The student was able to:

1. identify elements integrated in a mechatronic system;
2. specify the attributes of various sensors to integrate them into a mechatronic system;
3. design circuits to condition measured signals from data acquisition;
4. program a microcontroller to read sensor input signals, perform manipulations on this data, and make decisions relating to these inputs and send control signals to necessary hardware;
5. specify attributes of pneumatic and hydraulic actuators to integrate them into a mechatronic system;
6. specify attributes of mechanical actuators to integrate them into a mechatronic system;
7. specify attributes of motors to integrate them into a mechatronic system;
8. apply the fundamentals of digital logic for a mechatronic system;
9. program a Programmable Logic Controller (PLC) to control a mechatronic system;
10. design a mechatronic system from engineering requirements; and
11. use contemporary software packages for mechatronic systems.

In addition to the competencies, we polled the students on the effectiveness of the course structure. We asked them to respond to the level of effectiveness on a five-point scale (1 = Poor, 2 = Fair, 3 = Average, 4 = Good, 5 = Excellent) on the seven issues. The issues and the average is tallied as follows:

1. Homework exercises: 4.16.
2. Laboratory exercises: 3.95.
3. Group student teaching: 3.7.

4. Group design project: 4.80.
5. The collaborative approach: 4.47.
6. Team faculty teaching: 4.68.
7. The applied/theoretical mix of material: 4.16.

The most appreciated aspect of the course was the group design project with an average rating of 4.80. One student commented that the project was a "way to successfully work between disciplines." The students also appreciated the team teaching approach with two faculty. "Each faculty member had different things to offer. Appreciate the idea." The group student teaching exercise was rated the lowest at 3.7. One student commented that "Teaching helps in learning. It cleared some of my doubts about my topic." Another commented "Sometimes it was hard understanding the students." In responding to the applied/theoretical mix of the material the students rated it as 4.16, and one commented "I think this is extremely important to prepare students who are soon to encounter a work environment." As for the collaborative approach in general rated at 4.47, one student commented that "anything collaborative is worthwhile."

VI. REFLECTIONS

We believe that our first attempt at teaching an interdisciplinary course that involved both electrical and mechanical engineering students was a success. Both sets of students enjoyed the opportunity to learn from the other students. One of the most received components of the course was the design project. Students enjoyed the opportunity to design and build a working system on an interdisciplinary team. While the student teaching exercise was rated lowest on average, the student teachers found that they gained a deeper understanding of the details of the material. For example, the students who developed the microprocessor lectures stated that they really never understood the function of many of the assembly language instructions. From the professor's point of view, the students put far more time into creatively presenting the material than we would have. Thus, it shows that if you give students a chance to learn actively they will often exceed your expectations. We feel that the lower rating was more attributed to students having to adjust to multiple student-teacher styles.

When this course was taught again, we maintained the collaborative structure of the course. However, we made a few changes to the content of the course. We replaced the assembly language programming section with a microprocessor that is programmable using a higher language, BASIC. The students had difficulty programming in assembly language, and we thought that they gain the same benefit from using a higher-level language. Also incorporated more mechanical design of the "dynamic" system. The first year we focused more on integrating electrical components onto mechanical systems than the actual design of mechanical systems. Students would have liked the opportunity to work more on mechanisms and mechanical systems. We tried to include a greater balance in each aspect of mechatronics. Finally, we provided more guidance on the student teaching activity, which was highly received the second time. In fact, several students reported this as one of the most valuable aspects of the course.

In the future we will continue to make subtle changes in the course while maintaining the collaborative approach. We have found great value in having the course as interdisciplinary.

VII. CONCLUSION

This paper described collaborative learning techniques employed in an interdisciplinary course on mechatronics. The authors have found that there is a definite benefit to including interdisciplinary teams along with the interdisciplinary subject matter. Collaborative and active learning techniques proved effective in establishing desired levels of competencies in the students. Students also report that they believe the format is effective as well as enjoyable.

ACKNOWLEDGMENTS

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THE ROBOCKEY CUP: A LOOK AT MECHATRONICS EDUCATION IN 2009

The Robockey Cup

A Look at Mechatronics Education in 2009

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BY JONATHAN FIENE

Each fall, a group of intrepid students converge in a classroom on the third floor of the University of Pennsylvania's Towne Engineering Building for what they know will be one of the most challenging courses in their academic career. That first class begins with a discussion of where it will end. In particular, we talk about what they will accomplish in the final project, where they will design, fabricate, assemble, program, and debug small teams of autonomous hockey-playing robots, complete with wireless communications, infrared puck sensing, and enough onboard computational power to handle just about any task that can dream up. Most of the students look incredulous; after all, many of them have never built a circuit or written C code before.

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The Rules of the Game

We begin the semester by introducing the final project, and we shall do the same here.

The Rink

The Robockey rink resembles a generously rounded rectangle of approximately 240 × 120 cm, with 50-cm wide goals at each end. The rink is surrounded by 4-cm tall clear polycarbonate walls, and the surface of the rink is painted white with a wax finish to minimize friction.

The Puck

The object of each robot's affection is a 7.6-cm diameter custom-machined acrylic puck (as can be seen in Figures 1 and 2). The puck has three integrated ball casters, which allow it to easily glide the length of the rink. Inside the puck is a pair of lithium-polymer batteries, a small circuit board, and eight 940-nm infrared light-emitting diodes (LEDs) radiating outward. Sensing these LEDs will be the only way that the robots will be able to locate the puck on the field.

The Robots

Each team may field a team of up to three robots that must: 1) be shorter than 13 cm and remain within a 15-cm cylinder at all times; 2) be fully autonomous; 3) carry its own power source; 4) not constrain the puck's motion; 5) not intentionally damage the rink, the puck, or other robots; 6) not maliciously interfere with the wireless communication system; and 7) not emit or intentionally reflect infrared light.

Robot Localization System

A video camera located above the rink is used in combination with ARToolKit [1] to provide position data for each of the robots. To make them visible to the tracking system, each robot is required to have a threaded rod at its uppermost point to which a 12-cm-wide tracking fiducial can be attached (one of these can be seen atop the robot in Figure 1). When a robot is found by the tracking system, the corresponding X and Y location relative to the center of the rink is broadcast over the wireless system.

Wireless Communications

A local wireless network allows the tracking system and game controller to communicate with each robot while also allowing intrateam communication. Each robot in the tournament is assigned a unique 5-B address and must demonstrate an ability to follow single-byte hexadecimal game commands, such as 0xA1 for play, 0xA4 for pause, or 0xA5 for detangle (move randomly).

Game Play

A regulation Robockey match consists of two 2-min periods. Each period begins with a polo-style start, where the puck is placed in the center of the rink, while robots must be behind the lines located 80-cm from the center. Once the play command is issued, the robots are free to move about the field, with the objective of placing the puck into the opposing team's goal. If a goal is scored, the teams return to the starting positions, and the puck is relocated to the center of the rink. If the score is tied after two periods, a third period will commence. If the game is still tied after three periods, a sudden-death shootout is used to determine a winner.

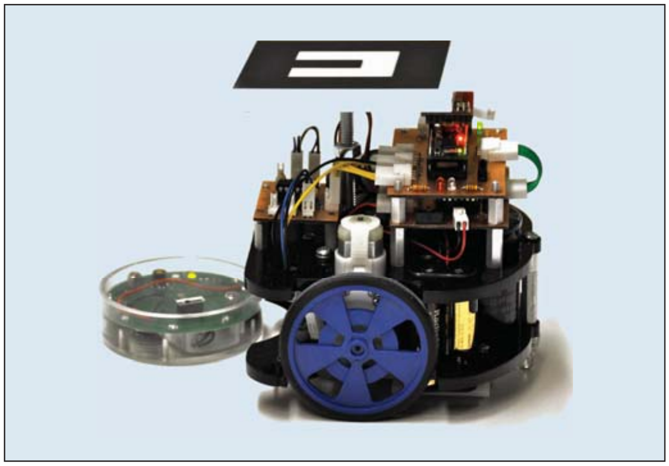

Figure 1. *A student-built autonomous hockey-playing robot.*

Motivation and Pedagogy

Each student brings his or her own set of motivations to the class, yet the added incentive of public competition causes a large percentage of the students to engage the material with significantly more vigor than might have been found otherwise. With the end goal for the semester firmly established, the students are asked to quickly generate a list of topics in which they think they will need to gain competency to succeed at Robockey. This list can seem daunting to many of the students, and it often includes motors, batteries, microcontrollers, programming, wireless communications, sensors, actuators, circuits and systems integration.

To take stock of the current knowledge of this diverse class, which typically draws an equal mix of graduate students and

Figure 2. *Two Robockey robots approaching the infrared-emitting puck.*

The Robockey rink resembles a generously rounded rectangle of approximately 240 × 120 cm, with 50-cm wide goals at each end.

undergraduates from a variety of engineering disciplines, an ungraded concept inventory is given out at the close of the first lecture. In addition to helping the teaching staff to know where students will need the most help, this exercise helps the students to know where they will need to focus their efforts. It is often the case where a few students are already well versed in one or two of the primary mechatronics categories; however, the majority of the students require substantial training in all areas, which include:

1) *Mechanical Design*: mobile–robot kinematics, motors, power transmission, gears, fasteners, basic structures, prototyping, sensors, mechanisms, and solenoids
2) *Electronics*: passive electrical components, voltage, current, resistance–capacitance (RC) filters, LEDs, phototransistors, op amps, comparators, semiconductors, transistors, MOSFETs, buttons, switches, inductive loads, digital logic, integrated circuits, noise, signal conditioning, wireless networks, analog-to-digital (A/D) conversion, sensors, and printed circuit board (PCB) design
3) *Programming*: the C programming language, binary, hexadecimal, memory, addressing, input/output, clocks/timers, pulsewidth modulation, A/D conversion, serial communications, interrupts, and event-driving programming.

Although there is an inherent challenge to both learning and teaching such a variety of material within a single semester, there are a number of interlocking elements (sensors, actuators, etc.) that bridge the gaps between the disciplines and help tie the material together. Approximately half of these topics can be taught effectively through traditional lectures and written assignments, whereas the remainder benefits significantly from hands-on experience, where the students can achieve a personal connection to the material [2]. To this end, a series of six small projects are introduced throughout the semester, ranging from a primer on electronic prototyping to a team project to build a small self-balancing robot.

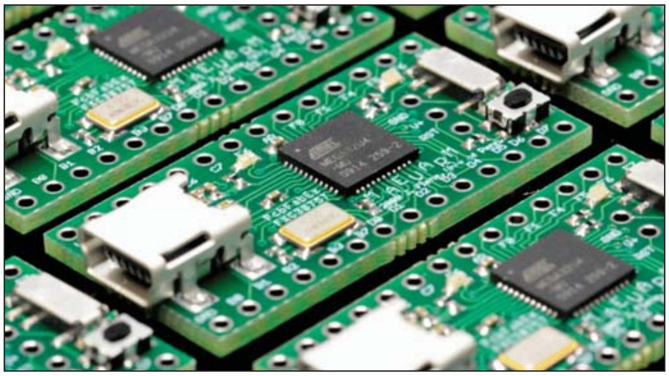

Figure 3. *The M1 custom microcontroller solution.*

Resources

To support this aggressive project and the breadth of course content requires significant infrastructure, including a relatively large dedicated laboratory space, complete with electronic test equipment (multimeters, oscilloscopes, power supplies, and function generators) an assortment of standard electronic components (resistors, capacitors, switches, ICs, etc.), mechanical prototyping and fabrication capabilities (laser cutters, mills, lathes, hand tools, etc.), project storage space, and a dedicated core of teaching assistants, most of whom are alumni from previous semesters.

In addition, one of the most important decisions for a course of this nature is the selection of a suitable microcontroller that the students will be able to embed into their designs. Given experience with a number of different commercially available packages, the decision was made to develop a custom solution based on the Atmel AVR processor. The result of this effort, known as the M1 [3], is shown in Figure 3. This two-layer board measures 1.8 × 4.0 cm and is built around the ATmega32U4 processor, which has 32 K of programmable flash, 1 K of electronically eraseable programmable read-only memory, 2.5 K of static random-access memory, 25 diode-protected general purpose input/output lines, four standard timer/counters, one high-speed timer, 12 channels of 10-b ADC, and a variety of serial communication channels, including universal serial bus (USB) (which can be used for direct PC-to-chip programming, as well as debugging). The chip uses a modified Harvard architecture, takes a nominal supply voltage of 5 V, and uses an 8-MHz external oscillator. The board has a built-in reset button, along with a bootloader/run switch and two LEDs that can be independently controlled. Completely assembled in moderate quantities for less than US$15 per board, this platform is well suited to students who are learning the art of microcontrollers.

Course Components

Having set the pedagogical requirements for the final project, and with an understanding of the existing infrastructure, it is a relatively straightforward process to track backwards through the semester, placing smaller projects, assignments, and lecture topics in such a way that the material roughly fits the hierarchy necessary to build the requisite knowledge base [4]. Looking specifically at the Fall semester of 2009, this process resulted in the following list of laboratories (L) and assignments (A):

- Week 1: Basic electronics
  - L1: Introduction and passive filters—familiarize students with the electronic test equipment in the mechatronics laboratory and then get them working with passive RC low-pass and high-pass filters
  - A1: Passive circuit analysis—solve problems related to equivalent resistance, voltage division, RC filter time constants, impedance matching, and filter design
- Weeks 2–3: Optoelectronics, sensors, actuators, semiconductors, inductive loads
  - L2: Beacon tracking—provide students with some fundamental experience prototyping simple circuits, using LEDs and phototransistors, and driving dc motors. The final portion of this laboratory requires students to design and built a two-device system, one of which is

capable of tracking the other using infrared light. Each object must obey certain size constraints, and no physical connection can be made between the two objects. Students are required to demonstrate their system to a member of the teaching staff within a standardized testing environment.

  - A2: Motors and switches—solve problems related to H-bridge switches, dc motors, bidirectional motor control, motor selection, and common motor drive circuits.
- Weeks 3–4: Digital logic, mechanical prototyping, transmissions, gears, feedback control, and op amps
  - L3: Maze—design, construct, and test the drive mechanics and circuitry for a small mobile robot to carry a 500-g mass through a maze using a remote control [see Figure 4(a) for one of the many solutions]. Those enrolled in the graduate section of the course are also required to design and build the controllers to drive the robots through the maze, including the development of a standard communications protocol.
  - A3: Op amps—solve problems including addition and subtraction circuits, integration and differentiation, and transresistance using operation amplifiers.
- Weeks 5–6: Microcontrollers, C, input/output, clocks, timers, A/D conversion
  - L4: Stroboscope—to familiarize students with the M1 microcontroller, they are given the task of building battery-powered strobe lights, where the frequency of the strobe is controlled using a potentiometer and the duty cycle is controlled using a small bank of switches.
  - A4: Localization—exploring one of the more challenging aspects of the Robockey system, students are given the task of developing four different methods by which they could track the location of a robot on a field. Solutions varied from overhead camera-based tracking and indoor GPS to embedding a grid of thousands of LEDs into the field, all flashing at different frequencies.
- Weeks 7–8: USB communication, advanced sensors, accelerometers, interrupts, digital filters
  - L5: Balancing robots—in this first team project, groups of three students design and build a fully contained two-wheeled self-balancing robot using the M1 microcontroller. Students are given a choice of sensors, including microelectromechanical systems-based Freescale MMA7361L triaxial accelerometers. One of the more successful solutions can be seen in Figure 4(b).
- Week 9: Event-driven programming, wireless communication
  - L6: Wireless Morse—to gain an understanding of basic wireless communication between multiple M1 boards, students are tasked with creating a simple wireless Morse code system to send and receive binary information between team members.
- Week 10: PCB design
  - A5: Puck challenge—to familiarize students with the PCB design process, the design of the circuit for the Robockey puck becomes a class project, where the best design will end up on the field. The specifications include geometric constraints, infrared emission characteristics, and power source selection.
- Weeks 11–14: Robockey—the final weeks of the class are devoted to milestones and deliverables for Robockey, including:
  - test of the robot's ability to follow game-play commands
  - demonstration of the robot interpreting localization signals to navigate itself to the center of the rink
  - friendly matches (minimum two per team)
  - preliminary rounds of the double-elimination tournament
  - public festival, including final rounds of the tournament.

> ***The object of each robot's affection is a 7.6-cm diameter custom-machined acrylic puck.***

2009 Robockey Results

Mechanical Design

The majority of the groups split their team of robots into two fast-moving "forwards" and a methodical, special-purpose "goalie." Although most teams quickly settled into the relatively standard differential-steering platform (as seen in Figure 1), there were some noticeable exceptions, such as the omnidirectional creation shown in Figure 2. To locate the puck, all of the teams incorporated outward-facing infrared phototransistors near ground level. Many teams relied on mechanical switches to determine when their robot had control of the puck,

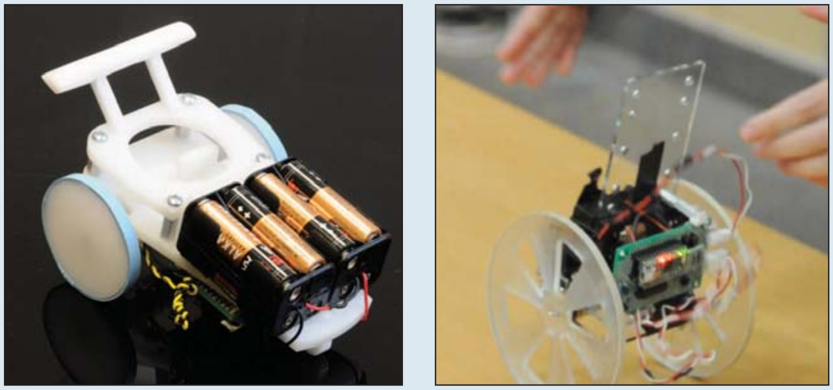
(a) (b)

Figure 4. *(a) One of the many maze-going robots built for L3 and (b) one of the balancing robots built for L5.*

Figure 5. *The 2009 MEAM 410/510 class at the conclusion of the Robockey Cup Tournament.*

while some built small break-beam sensors across the puck concavity. A few of the teams included a kicking mechanism using a dc solenoid and return spring. All teams made liberal use of laser-cut acrylic and mechanical fasteners in the construction of their robots, allowing for rapid iteration, assembly, and disassembly.

Electronics

All of the robots included an M1 microcontroller and a wireless module. Beyond that, most teams chose to use H-bridge ICs to drive the wheel motors, and the remainder of the circuitry focused on power conditioning, analog signal filtering, and digital control. Although a few of the teams chose to design PCBs, most relied on hand-soldering.

Programming

While it was the least visible of the elements in the Robockey robots, the code that students wrote to control their robots was certainly the most decisive factor in the overall performance of the teams. While certain functionality was explicitly required (such as obedience to game play commands), the exact implementation of the control algorithms varied widely from team to team. The programming was often the most difficult of the components for students to grasp and master, and while it was a goal for most, only a handful of the teams were able to successfully implement interrobot strategy (field location, passing, etc.).

Strategy

With the exception of specialized goalies, most of the robots attempted to execute a similar strategy: wait for the play command; search for and drive toward the puck; get the puck, drive toward the opposite goal; and shoot the puck into the goal. With as many as six robots on the field all executing a similar strategy, it was never quite that easy.

Observations and Future Directions

"The student projects went on until 10:00 p.m. The excitement in [the auditorium] was incredible. You could hear the cheers as goals were scored or missed from outside the building. The robot designs were clever and the control algorithms were ingenious."

"It is the capstone course to take for any engineer, because it involves so many interdisciplinary skills from mechanical engineering, electrical engineering, computer science, and robotics. I have been challenged by this course and broadened my breadth of knowledge of all these disciplines."

"I wish more engineering courses were like this, with a mix of theory and a great hands-on component."

Although it can be difficult to quantify the overall effect of any course, the aforementioned quotes speak volumes about the impact that can be achieved.

This semester marked the second running of the Robockey tournament, and given the positive feedback and outcomes, it will likely continue for some time. Moving forward, it is critically important that we stay abreast of current technology, and efforts will certainly be made to reduce the workload, as many students do report that it is one of the most time-consuming courses that they have ever taken.

Additional details for all of the projects and assignments, along with course lecture materials and information on the custom M1 microcontroller board can be found at http://medesign.seas.upenn.edu.

Keywords

Education, pedagogy, microcontrollers, robots.

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