Proceedings of IMECE2002
ASME International Mechanical Engineering Congress & Exposition
November 17–22, 2002, New Orleans, Louisiana

IMECE2002-39469

# TEACHING OF MECHATRONICS THROUGH AN ELECTIVE COURSE

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## ABSTRACT

A mechatronics course has been recently introduced as a 4th year elective at the University of Saskatchewan Department of Mechanical Engineering. The necessity and the rational for this training are reviewed. A curriculum for the course is proposed supported by student feedback following its first year of introduction. The curriculum and the structure of the course is such that training in mechatronics may be provided through an elective course. Notwithstanding, the merits of establishing a degree in mechatronics are discussed given the strong industrial demand for this topic.

## I. INTRODUCTION

Mature engineering companies that are involved in one-off projects have long recognized the importance of process definition and the establishment of organizational structures that support their business and engineering processes. One common organizational structure involves a matrix organization within a site or a specific product line. Staffing within a matrix organization widely involves the allocation of dedicated staff and resources to projects from departments that support them. The day-to-day management of these resources is the responsibility of a project or program manager; while the training and the strategic development and allocation of staff are made by departments. Ideally, the staff allocated to projects should remain in place until the completion of their task and as needed. Unfortunately, such structures proved somewhat unstable in their staffing in the late 1990's given the rapid economic expansion of that decade and the reluctance of firms in expanding their capacities partly due to the scarcity of resources and partly due to the expectation of forecasted potential downturns in their market sectors. In most firms the reality of engineering practices thus often deviated substantively from the ideals governing their organizational structure. In a majority of organizations with matrix structures, resources ended up being shared between programs and were often scarce. In such environments, programs compete for resources and due to pressing deadlines; end up with allocating tasks to staff that may not be adequately trained in a discipline. To compound the problem, products need functional differentiation due to the competitive markets faced by most industrial firms, and require product design using a multitude of disciplines. Subsequently in the 1990's engineering managers became increasingly cognizant of the need for recruiting staff with multidisciplinary expertise. These allow a greater level of flexibility in task assignment and are capable of performing effective trade-off analysis in product design involving functional differentiation. Universities responded to this need by developing engineering courses that involved multidisciplinary training and more specifically in the area of Mechatronics. A proposed training in mechatronics and its associated challenges are discussed in section II. Sections III and IV present the curriculum of a course taught at the authors' institution and its teaching philosophy. Student feedback from the course and discussions are presented in Section V. Concluding remarks are contained in Section VI.

## II. THE EXPECTATIONS AND THE CHALLENGES ASSOCIATED WITH A COURSE IN MECHATRONICS

The expectations from the field of mechatronics are diverse and in many institutions somewhat ambiguous. Nonetheless the ASME definition for mechatronics points to an engineer with skills in a range of combined topics from mechanical engineering, electrical engineering, and computer science. The effectiveness of an engineer with a multidisciplinary training is the breadth of knowledge. This breadth of knowledge albeit product line specific has been traditionally attributed to Systems Engineers. Systems engineers in industry have a portfolio of skills that typically include product line specific technical knowledge acquired through years of industrial experience and customer contact, knowledge of systems engineering process, system design or synthesis, interface of subsystems, multidisciplinary technical capability, and systems engineering management. It may be argued that mechatronics is a subset of systems engineering and as such a strategic advantage may be gained by incumbents by including concepts from systems engineering into their mechatronics training. A generic suggested profile for an engineer with a mechatronics training that is in line with ASME's definition would include one with an understanding of the following:

- systems engineering process and an appreciation of the constraints faced in a real engineering environment;
- requirements capture and analysis;
- dynamic analysis and modeling;
- control design involving PID analog and digital controllers;
- sensitivity analysis;
- trade-off analysis;
- microcomputers and microcontrollers;
- fundamentals of software engineering and software development;
- mechanical design;
- electrical circuits;
- actuation systems
- instrumentation; and
- transducers and sensors.

Provision of such training is not without its challenges. Universities need to ensure a tangible load for students while ensuring a substantive and in-depth coverage. To overcome these, the following possibilities have been considered:

1. training of students in their choice of specialization such as mechanical engineering through core courses and provision of elective courses in mechatronics;
2. establishing a mechatronics stream through core courses carefully chosen from various departments; or
3. designing a specific curriculum for a degree in mechatronics.

Instituting change in Universities for such training is challenging and at its inception needs to be often championed by a visionary Dean or driven by pressure from industry backed with provision of funds.

## III. THE MECHATRONICS TRAINING AT THE UNIVERSITY OF SASKATCHEWAN

The University of Saskatchewan recently initiated a training in mechatronics for its undergraduates by providing an elective course (choice 1 as listed in the previous section). The curriculum for this course largely satisfies the objectives and expectations listed in Section II and includes the following:

- Introduction to Mechatronics
- Systems Engineering Process
- Systems Engineering Design Process
    - Functional Architecture
    - Physical Architecture
    - Operational Architecture
- Introduction to Mechatronics Design
- System Modeling and Simulation
- Electrical Circuits and Systems
- Microprocessors and Microsontrollers
- PIC Microcontrollers
- PIC Assembler Code
- Software Design
- Actuation Systems
    - Electrical Motors
    - Fluid Power
    - Pneumatic Systems
    - Piezoelectric Actuators
- Digital Control and Signal Processing
- Instrumentation
- Sensors
- Introduction to Intelligent Systems

A customized set of course notes has been produced for the course. The course however does use a text for parts of the material covered as follows:

- Mechatronics, 2nd Edition, W. Bolton, Prentice Hall, 2000, [1].

Other textbooks used by the course include references [2,3,4,5,6,7].

The course relies on prerequisites that establish some of the fundamental concepts associated with linear systems and their analysis, mechanical design, modeling of electromechanical systems, electrical systems, and control. In practice, most students attending the course have a good understanding of computers and programming.

Two projects that are used for experiential learning form an important aspect of this course. The first project involves modeling, analysis, simulation of an electromechanical system using the Matlab/Simulink software and the design of a digital controller. The second project is hands-on and involves building a computer controlled laboratory scale car. The students are split into project groups of four and are provided with a kit at an approximate cost of $3000 that includes:

- Parts that can be assembled in various configurations to build the frame of a car;
- Choice of two steering systems;
- DC and stepper electrical motors;
- Optical and eddy sensors;
- PIC microcontroller card (PIC16F877); and
- Software platform for assembly language programming of the PIC microcontroller.

The students can assemble and build the car in many configurations. The concepts such as instrumentation and microcontrollers that are needed for building the car are covered in class. The students are provided with 2 hours of supervised laboratory session per week. These sessions enable the students to resolve difficulties that they may encounter through assistance from instructors and laboratory technicians.

## IV. TEACHING STRATEGIES

An effective strategy for teaching is combining theory with experiential methods. This constitutes the core of the teaching philosophy used in the Mechatronics course. The connection between the course material/learning processes, and that known and/or experienced in industry is stressed through a review of the engineering process through case studies. This starting point is instrumental in making the course stimulating, exciting, and interesting.

Such connections are sometimes difficult for educators to find, and it is by teaching our students in part to search out this connection that they, themselves, can learn through personal reflection on experience. In this course in addition to case studies, a project is used to provide the students with an opportunity to connect educational material with their own hand-on/life-world experience. Through using this approach to teaching, students are given the opportunity to have direct access and engagement with the material, as well as have a self-defined ownership of the subject.

A variety of active teaching strategies are used in this course as follows:

- *LECTURING*: 3 hours of lectures per week complemented by course notes that are posted on a web page are provided to students. Students are required to participate during the lectures. They only write when examples are being presented in class. The lectures are designed to make connections between theory, industrial practices and material needed for their project.
- *COLLABORATIVE LEARNING*: The students are organized into groups of 4. Group assignments are an important component of the course and reflect the teamwork needed in industrial environments. The students learn the importance of group process. Nonetheless, the success of collaborative learning requires ongoing monitoring and facilitation of student groups.
- *METHODS FOR TEACHING CRITICAL THINKING*: The lectures include class discussions around examples and case studies. These class discussions are the first and foremost way that critical thinking is nurtured in lectures.
- *FREQUENT BUT MANAGEABLE ASSIGNMENTS*: Students tend to keep up with the learning of course material if asked to do frequent but manageable assignments. They also learn better, as they are actually actively learning the material in a continuous manner. In this class, the students hand in 6 assignments.
- *EXPERIENTIAL LEARNING*: the main method for establishing experiential learning in this class is through the two projects performed by students. One of the projects involves interaction with outside through the Internet. The students get the opportunity to problem solve and improvise should they choose to by considering various design options. They also get to learn cooperatively and collaboratively and to actively participate in the learning process.

The student groups are provided with supporting software, computing facilities, and hardware that support both the theoretical and applied aspects of the course.

## V. INSTRUCTOR OBSERVATIONS AND STUDENT FEEDBACK

The student feedback on the course has been generally very favorable. Both the course and its project were ranked as very good (4 on a scale of 1 to 5 that comprised the option: 1-very poor, 2-poor, 3-average, 4-very good, and 5-excellent). The students' suggestions for course improvements were as follows:

- intermediate milestones to be enforced on students in order to prevent them from falling behind in their project work;
- more emphasis and training to be provided in assembly language programming;
- improvements to be made in the quality of some of parts provided to students in their project; and
- high level language to be used for programming of the PIC microcontroller.

The instructor's observation indicates that most students have a generally good understanding of computers and are able to understand the concepts associated with microcontrollers and their architecture. Assembly language programming however despite its introduction in the course is the main source of difficulty for the students given the relatively low level of emphasis that can be placed on this subject given time constraints. It is nonetheless an important tool for teaching of microprocessor and microcontroller architecture. As such a future strategy to be adopted is to retain the training that is built into the course, provide the students with a basic software solution in the form of an assembly language program and, require them to translate this program into a high level language such as Basic that can easily be understood and applied by students. Alternatively, assembly language programming covered by a computing course should be specified as prerequisite.

The students were divided into groups of 4 and despite their previous exposure to group projects (twice in their prior 4 years of university studies), at least 25% of the students experienced problems that can be associated with group dynamics.

## VI. CONCLUSIONS

A mechatronics course was introduced as a final year elective at the Department of Mechanical Engineering, University of Saskatchewan. The curriculum used by the course, the associated course notes, and the hands-on supervised projects have enabled this class to require minimal prerequisites. As such, it has been possible to provide training in mechatronics to mechanical engineering students through an elective course rather than a mechatronics stream. The main source of technical difficulty for mechanical engineering students in this course has been assembly language programming. This may be eliminated by imposing a prerequisite or preferably by forcing the students to translate, rather than design, codes from an assembly language to an easily understood high level language such as basic. This enables the students to understand the microcontroller architecture without having to write assembly language programs.

Despite the success of this course, it should be noted that the trend in product development strongly points to the need for broader multidisciplinary training. As such awarding of degrees in mechatronics should be strongly considered by universities. For this to occur, the departmentalized structure of universities and structural barriers that exist within such institutions should be reconsidered given the lessons learned by industry. Mechatronics has its roots in industry and as such it can be concluded that a mechatronics course is market driven. It must hence evolve not just with technology but also with the organizational maturity of industries. Establishment of an infrastructure for the teaching of mechatronics would enhance the ability of universities to relate more closely to industrial need.

## VII. REFERENCES

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