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A Proposed Learner-Centered Mechatronics Engineering Instructional Program

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Abstract – This paper examines the need and requirements for a mechatronics degree program. The results of a survey of the few existing programs in this field are provided. Then, using a case study example for Virginia Tech, a proposed mechatronics curriculum based on a learner-centered paradigm is described. The curriculum combines existing courses in mechanical, electrical, and computer engineering with new, hands-on courses to provide students with a chance to practice and explore the subject matter in ways consistent with the demands of both industry and accreditation. This program, if implemented, could provide a university with a unique offering to attract top students by better preparing them for the types of problems they will encounter in the modern world.

Keywords: Mechatronics, Education, Learner-Centered.

INTRODUCTION

Mechatronics is a rapidly emerging field that combines mechanical, electrical, and computer engineering [1]. Mechatronic systems use the abilities of computer or microprocessor based automatic control to enhance the operation of mechanical systems [2]. Mechatronics is often associated with robotic systems but can also be found in applications ranging from automobiles to electric toothbrushes. As more and more industries are expanding their implementations of mechatronic systems, there is an increasing demand for engineers with the multidisciplinary experience necessary to design these types of systems.

Most current engineering curriculums, especially in the United States, focus on the more traditional areas of engineering: mechanical engineers learn about mechanics, stress analysis, thermal sciences, and fluid dynamics; electrical engineers learn about electronic circuits, communications, and power transfer systems; and computer engineers learn about integrated circuits and software. Mechatronic designs often include aspects of all of these fields and require engineers with a broad enough base of knowledge to understand how to integrate these varied disciplines into working systems. In this respect, mechatronics requires engineers who can comprehend and perform multidisciplinary systems engineering tasks in ways not well covered in traditional curricula [3].

Outside of the United States, especially in Europe and Asia, the solution to this need has been found in the form of multidisciplinary undergraduate mechatronics curricula. These curricula draw aspects from each of the traditional disciplines to expose students to a broad enough range of topics to allow them to become successful mechatronics engineers.

A very active interest in mechatronics engineering exists in Turkey, for example. Industrial demands have led to the creation of programs in mechatronics education from the high school level through graduate school [4]. Turkish universities have taken a variety of approaches from offering courses as a subset of mechanical engineering to the case of Antilim University's separate mechatronics department [4][5]. Mechatronics has also become very popular in Germany, with the University of Applied Sciences in Bochum pioneering the discipline [6]. Mechatronics programs are also being developed in many other countries including: Jordan, Romania, Kosovo, and China [7][8][9][10].

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As of this writing (2009), however, adoption of this type of curricula in the United States has been very slow. Many schools, such as the University of South Carolina and the University of Utah, offer mechatronics programs as a subset of mechanical engineering [11][12]. Only a few schools, however, including California State University Chico, Lawrence Technological University, Southern Polytechnic State University, and North Carolina State University (in conjunction with the University of North Carolina at Asheville) offer complete undergraduate mechatronics degree programs [13][14][15][16]. These schools represent only a very small proportion of the engineering students who graduate in US schools each year.

In an attempt to promote the expansion of mechatronics curricula in the United States, this work will propose an undergraduate mechatronics curriculum for Virginia Tech. The curriculum will be based on a learner-centered set of educational objectives and be structured in such ways as to permit usage of existing classes in traditional disciplines. New classes required to complete the learning objectives will be outlined and compliance with accreditation requirements will be discussed.

METHODOLOGY

The goal of this work is to demonstrate the need for an undergraduate mechatronics degree program. Using Virginia Tech as a case study, it will be shown that a broad-based, learner-centered mechatronics curriculum that meets established accreditation criteria can be established largely from existing classes.

An educational curriculum such as the proposed BS in Mechatronics Engineering consists of a set of required and recommended courses that, once completed by a student, are deemed to have conferred the knowledge necessary to perform in the field and receive a degree. The standard for evaluating engineering curricula is defined by the Accreditation Board for Engineering and Technology (ABET). This organization evaluates programs against a list of published criteria and confers accreditation status on those that demonstrate the required quality standards. ABET accreditation is a necessity for a program to achieve prestige in the field and recruit students.

Since ABET accreditation has become valued and respected, it is important to design the curriculum based on ABET requirements and standards [17][18]. The first step in this process is the establishment of a set of educational objectives subject to certain requirements.

Since individual course syllabi also factor into the accreditation process and since it is expensive for the university to offer new courses, the next step is to analyze the existing engineering curricula at Virginia Tech to choose existing courses that meet as many of the educational objectives as possible. To address the learning objectives that existing courses cannot meet additional courses will be outlined to fill those needs.

Research has also shown that applying learner-centered techniques can dramatically improve students' capability to learn new material [19][20]. The curriculum will therefore attempt to incorporate these principles where possible.

Educational Objectives

In addition to the base ABET requirements and taking into account the principles of mechatronics, the following specific educational objectives are proposed for a mechatronics curriculum:

a) An ability to interpret and analyze mechanical systems including static structures and dynamic elements.

b) An understanding of and ability to analyze conductive, radiative, and convective heat transfer.

c) An ability to construct and analyze basic and applied electrical circuits including active and passive elements.

d) An understanding of and ability to program computers and microcontrollers using both low and high-level languages.

e) An understanding of the principles of software architectures and design principles.

f) An understanding of and ability to apply classical control theory.

g) A knowledge of wired and wireless communication architectures and protocols.

h) Knowledge of digital and discrete mathematics and systems.

i) An ability to use sensors to collect and analyze data.

j) An ability to use engineering principles to analyze engineering problems to determine requirements and possible solutions.

k) An ability to design mechatronic systems including mechanical, electrical, and software components.

l) An understanding of the principles of system-level design and integration.

Curriculum Analysis

An analysis of the curricula of the component disciplines of mechatronics reveals many commonalities. Electrical, computer, and mechanical engineering at Virginia Tech all include 130-132 hours of required courses and electives. The breakdown of courses is shown in Table 1 [21][22].

Table 1: Breakdown of Existing Curricula

Course Type	# of hours
Engineering Education	6-7
Humanities/Liberal Education	22
Math	18
Basic Science	12
Required In-Major Courses	56-59
Technical Electives	15-17

Major topic areas for each curriculum include:

Mechanical Engineering: mechanics, dynamics, heat transfer, thermodynamics, mechanical design, circuits, and measurements

Electrical Engineering: circuits, digital systems, communications systems, power systems, and electronics

Computer Engineering: circuits, digital systems, communications systems, microcontroller systems, software architectures

RESULTS

The proposed curriculum would draw courses from the existing mechanical, electrical and computer engineering curricula to complete the list of courses shown in Table 2 and in graphical form in Figure 1. Core courses including engineering education, liberal education, and the basic sciences would remain unchanged. For most students this would result in no differentiation during the freshman year of coursework. During the sophomore year, students would begin to take introductory courses in electrical and mechanical theory including statics, dynamics, and circuits. Additionally, a new sophomore-level Introduction to Mechatronics course is proposed to introduce students to the field.

Junior level coursework would include system dynamics, mechanics, thermal/fluid systems, and mechanical design from mechanical engineering. Electrical and software engineering courses would include computer architectures, electronics, and micro system design. Additionally, a mechatronics specific writing-intensive laboratory course would be created to emphasize laboratory skills and measurement technologies.

The senior year would include control engineering, heat and mass transfer, digital design, and embedded system design. Additionally, a second semester of the mechatronics laboratory and a technical elective from mechanical, electrical, or computer engineering would be required. The last major focus of the senior year would consist of a capstone design project and technical electives from an approved list to allow students to expand and focus their expertise to meet their interests. The capstone course would be based on and possibly dual-listed with the mechanical engineering capstone design course. It would consist of a two semester sequence in which the students are required to work in teams to design and build a solution to a real-world engineering problem. For further details on the courses, the reader is encouraged to visit the Virginia Tech websites to view detailed course descriptions [21][22].

The proposed curriculum contains a total of 130 semester hours of coursework spread over four years. Table 3 provides a breakdown of the curriculum which may be compared to the existing curricula in Table 1. The base university requirements are the same, but the number of required in-major courses has increased while the number of electives has decreased due to the broad-based requirements of mechatronics. The program is similar to, but not directly modeled on any other specific Mechatronics Engineering program.

Table 3: Breakdown of Proposed Curriculum

Course Type		# of hours
Engineering Education		4
Humanities/Liberal Education		22
Math		18
Basic Science		12
Required In-Major Courses		71
	Mechanical Engineering	24
	Electrical Engineering	17
	Mechatronics Engineering	9
	Design Focused	21
Technical Electives		3

Although no ABET classification currently exists for Mechatronics Engineering, it is believed that this curriculum could reasonably be accredited. ABET accreditation is done on the program level, and the proposed curriculum includes all of the required ABET program outcomes as specified in the “Criteria for Accrediting Engineering Programs” publication [18]. The accreditation process would be aided by the fact that most of the courses are currently part of accredited programs and are already documented to ABET standards.

New Courses

One of the most critical courses to the new mechatronics curriculum would be the sophomore level Introduction to Mechatronics course. The objective of this course would be to provide students an introduction to the field and encourage them to relate their prior experiences to the new material they are being presented with. The class would be hands-on and would involve a lab component in which the students are required to solve simple mechatronics problems involving microprocessors, sensors, mechanical actuators, and control systems. The main goal of the course would be to demonstrate the potential uses of mechatronics to the students and to get them excited about the possibilities of applying material in their other courses.

To meet the educational objectives involving measurement and data processing, a new two semester junior/senior lab course is proposed. This course would require students to apply mechatronics to design and collect data with sensor systems. The laboratory assignments would be drawn from both mechanical and electrical engineering. The students would be required to design and build instrumentation systems to collect required data from controlled experiments. Additionally, to meet ABET communication skills requirements, this would be a writing and presentation intensive course.

Learner-Centered Aspects

Learner-centered instruction is considered a very important part of the curriculum. As discussed by Wankat, it is important to enable the students use metacognition to monitor their learning progress [19]. In order to do this, students must be able to relate the new concepts and skills that they are learning to their own previous knowledge and experience [19]. One method for doing this in engineering education is through problem-based learning where the students learn concepts by applying them to solving open-ended domain-oriented problems [20].

The primary learner-centered aspect of the curriculum is the emphasis on hands-on laboratory experiments and in the design and implementation of systems. The curriculum includes hands-on aspects during every academic year. The freshman engineering education courses introduce students to engineering by means of group design projects. The proposed sophomore level introductory course will encourage students to explore different aspects of mechatronics and to relate mechatronic principles to their own prior experiences.

The junior/senior level lab courses will require students to apply the theoretical knowledge acquired in the class room to solve problems presented in the form of laboratory experiments. In the senior level capstone courses the students will be guided in an open-ended design problem in which they will be able to apply the skills and techniques learned in their prior coursework and experience.

CONCLUSIONS

Mechatronics is a rapidly expanding field that fuses mechanical, electrical, and computer engineering. In order to impart the skill set necessary for students to become successful mechatronics engineers, it is necessary to cover aspects of the traditional curricula in a non-traditional combination. As is being increasing recognized both in the United States and around the world, one of the best ways to do this is the creation of a mechatronics degree program at the undergraduate level.

The proposed curriculum meets all of the learning proposed objectives and is posited to provide a good basic knowledge of mechatronics engineering. The curriculum is particularly heavy in hands-on and design related courses that encourage the student to explore mechatronics and gain practical experience with mechatronic systems. Given the emphasis on system integration in mechatronics, this experience is vital to post-educational success in the field. Additionally, as discussed, interactive learner-centered education enhances learning and enables students to integrate the knowledge at a level beyond rote memorization.

Due to the breadth of the field of mechatronics, it is nearly impossible to cover every topic in four-year degree program. The 130 semester hour total is in line with other engineering curricula and provides a good balance of breadth of knowledge versus feasibility from both the student's and the university's perspective. One potential weakness of the proposed curriculum is that the breadth and focus on design-based courses may result in students lacking knowledge of the in depth theory behind the components that they are working with. This weakness in theoretical basis could be a handicap to students interested in graduate studies careers in research. Due to the limits of the four-year program, any expansion of theoretical coursework would require the degree to become either a 5-year bachelors or 5-year BS/MS program.

Due to the extensive reuse of existing courses, it would likely be possible to implement this program that would offer the university a significant competitive advantage at a relatively low cost. This is an important consideration in an age of university budget limitations. Mechatronics Engineering could be established as a separate department or could logically be administered under the aegis of one of the existing departments. Additionally, the use of existing coursework would potentially enable the program to be initiated as a certificate program in mechanical or electrical engineering until a critical mass of students can be integrated into the program.

Using Virginia Tech as an example, it has been shown that it is possible to assemble a complete curriculum for a mechatronics baccalaureate degree using mostly existing courses from the traditional disciplines. It is hoped that Virginia Tech and other universities will be able to use this proposal as a guide to foster the expansion of and/or creation of mechatronics degree programs.

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Janis Terpenny

Janis Terpenny is a Professor in Mechanical Engineering and Engineering Education, and an affiliate faculty of Industrial & Systems Engineering at Virginia Tech. She is Director of the NSF Center for e-Design, a multi-university I/UCRC center. Her research focuses on process, methods, and tools for early design and on engineering design education. She is a member of ASEE, ASME, IIE, and Alpha Pi Mu and is the Design Economics area editor for The Engineering Economist and the Associate Editor for Design Education for the ASME Journal of Mechanical Design.

Figure 1: Flowchart of Proposed Mechatronics Curriculum

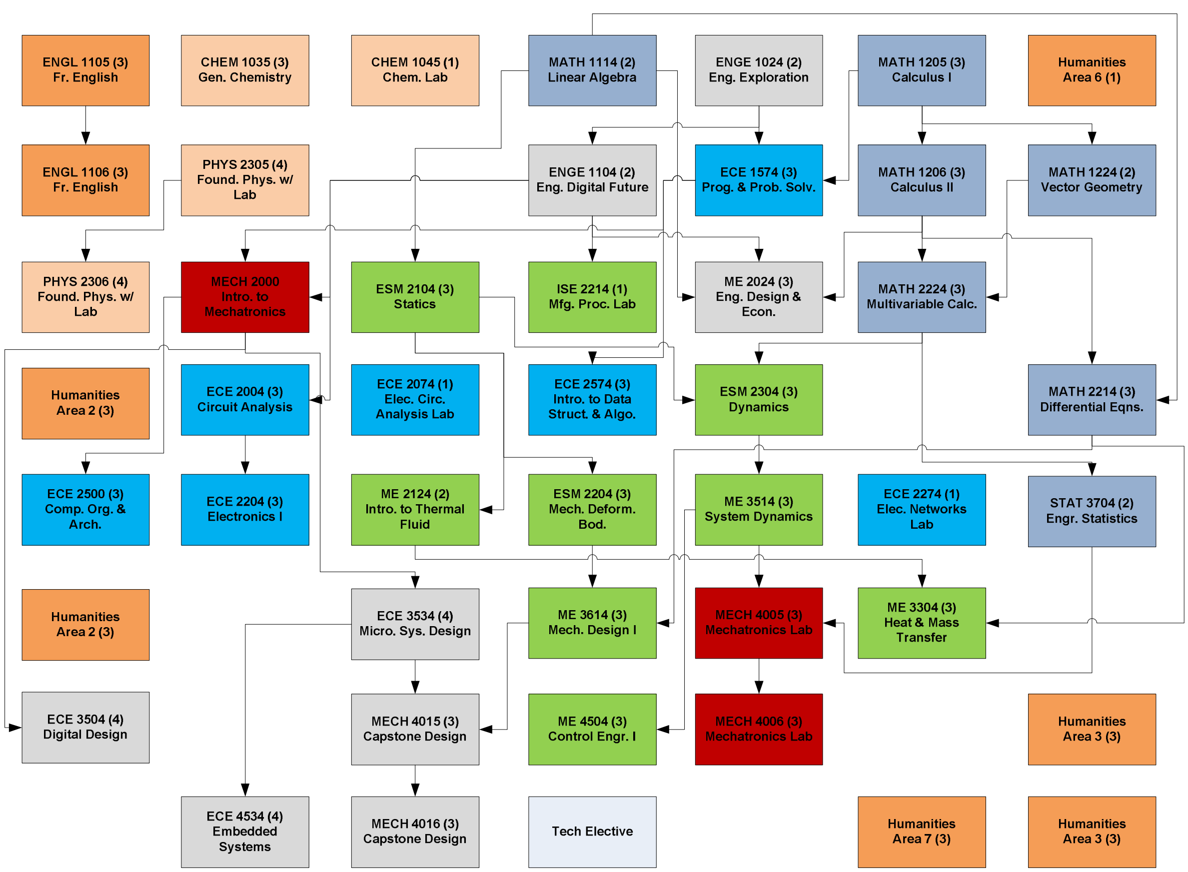

TABLE 2: PROPOSED CURRICULUM

Freshman Year			
Fall		Spring	
ENGE 1024	2	ENGL 1106	3
Eng Exploration		Freshman English	
CHEM 1035	3	MATH 1224	2
Gen Chemistry		Vector Geometry	
CHEM 1045	1	MATH 1206	3
Gen Chemistry Lab		Calculus II	
ENGL 1105	3	PHYS 2305	4
Freshman English		Found Phys w/Lab	
MATH 1114	2	ENGE 1104	2
Linear Algebra		Eng. Digital Future	
MATH 1205	3	ECE 1574	3
Calculus I		Prog. & Prob. Solving	
Hum. Area 6	1		
TOTAL	15	TOTAL	17

Sophomore Year			
Fall		Spring	
PHYS 2306	4	MATH 2224	3
Found Phys w/Lab		Multivariable Calculus	
MATH 2214	3	ECE 2004	3
Diff Equations		Circuit Analysis	
ME 2024	3	ECE 2074	1
Engr Design & Econ		Elec Circ Analysis Lab	
ESM 2104	3	ESM 2304	3
Statics		Dynamics	
MECH 2000	3	ECE 2574	3
Intro to Mechatronics		Data Struct. & Algo.	
ISE 2214	1		
Mfg Proc Lab			
		Hum. Area 2	3
TOTAL	17	TOTAL	16

Junior Year			
Fall		Spring	
ME 2124	2	MECH 4005	3
Intro Thermal Fluid		Mechatronics Lab	
ME 3514	3	ECE 3534	4
System Dynamics		Micro Sys Design	
ESM 2204	3	ME 3614	3
Mech. Deform Bodies		Mech. Design I	
ECE 2204	3	ME 3304	3
Electronics I		Heat & Mass Transfer	
ECE 2274	1		
EE Circuits Lab			
ECE 2500	3		
Comp Org. & Arch.			
STAT 3704	2		
Engineering Statistics		Hum. Area 2	3
TOTAL	17	TOTAL	16

Senior Year			
Fall		Spring	
MECH 4015	3	MECH 4016	3
Capstone Design		Capstone Design	
MECH 4006	3	ECE 4534	4
Mechatronics Lab		Embedded Systems	
ME 4504	3	Tech Elective	3
Control Engineering I			
ECE 3504	4		
Digital Design		Hum. Area 7	3
Hum. Area 3	3	Hum. Area 3	3
TOTAL	16	TOTAL	16

Program Total: 130 semester hours