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Design and Implementation of a Novel Biomedical Systems Engineering Concentration Within An Established And EAC-of-ABET Accredited Electromechanical Engineering Program

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ABSTRACT: This paper reports on the establishment of a faculty-driven, high-quality biomedical systems engineering concentration within an established and EAC-of-ABET accredited five-year interdisciplinary electromechanical engineering program at Wentworth Institute of Technology in Boston. The authors describe the uncommon context in which this concentration was established, the preparation, the market research, the competitive landscape, the resources needed, and the curriculum. In addition, the authors provide their thoughts and tips on duplicating this endeavor at other institutions. The authors also discuss scaling up this experience to other established engineering programs where other non-engineering subspecialties can be implemented in order to bestow great additional value to the newly graduated engineer.

Introduction:
A faculty-driven, high-quality biomedical systems engineering concentration was implemented within an established and EAC-of-ABET accredited five-year interdisciplinary electromechanical engineering program. Of note is that under EAC rules, the existing electromechanical engineering program had simultaneously met the accreditation criteria for electrical engineering and for mechanical engineering. The graduates of this program are true interdisciplinary engineers. A graduate of this program is as comfortable in tackling a thermo-fluid problem as he/she is comfortable in designing the electronic hardware and writing the control software to control a mechanical apparatus. In addition, the graduates have excellent laboratory and machine shop skills.

A biomedical systems engineering specialization was established in the form of a concentration within a well established electromechanical engineering program. The addition of the concentration required only limited additional resources. The result is a high-quality program that is competitive with other biomedical engineering programs offered in Massachusetts, and the program has attracted a substantial number of students, and has expanded opportunities for our graduates. The Electromechanical Engineering Faculty Committee[1], composed of eleven faculty members drawn from various disciplines, thoroughly researched, planned, and obtained administrative approval for the program, implemented, and is continuously assessing and fine-tuning this novel concentration. The endeavor was very much faculty driven. The faculty exercised care so that the addition of the new concentration did not alter or weaken the structure of the existing electromechanical engineering program but rather strengthened it, and provided greater opportunities for the graduates. The choice of elective courses from the life sciences,

co-op employment in the biomedical field, and design projects with life-science applications made he implementation of this concentration possible. The graduates continue to receive their Bachelor of Science in Electromechanical Engineering but with added strength in biomedical engineering--the student's transcripts will indicate the student's completion of the biomedical systems engineering concentration.

Historically, many of our Electromechanical Engineering students have shown an interest in biomedical engineering by choosing their junior and capstone design projects in biomedical engineering. Some of these projects were outstanding and won top regional awards from ASEE, ASME, and IEEE. There was a clear interest by the electromechanical engineering students in expanding their knowledge into biomedical applications. In addition, a number of faculty members have an interest in biomedical engineering, and had conducted research in ultrasonics, microelectromechanical systems (MEMS) in biomechanics, and medical devices. Finally, within a five mile radius of Wentworth Institute of Technology in Boston, there exists the greatest concentration in the U.S. of world-renowned hospitals, biotechnology and medical device firms. The faculty assembled an external interdisciplinary Industrial and Professional Advisory board of the highest caliber to provide advice and recommendations on the major issues related to the creation of the new concentration.

Feasibility Study:
A formal survey of all electromechanical engineering students at our institution was conducted. The results indicated a strong interest in a biomedical systems engineering concentration within the existing electromechanical engineering program. A study of the available resources also indicated that a concentration in Biomedical Systems Engineering offered to the electromechanical engineering majors was indeed feasible. It was confirmed that Wentworth had all the resources, human and material, to initiate such a set of courses with minimal risks and significant anticipated benefits. Also, given the location of Wentworth in the heart of the Longwood Medical Area, the potential existed for extensive collaboration in the form of co-op and research projects. In addition, as described in the following sections, the labor market and constituency and available resources were researched, and were found to be favorable to introduction of the biomedical program.

The labor market:
The U.S. Bureau of Labor Statistics (Department of Labor) indicated in its 2005-2006 edition of the *Occupational Outlook Handbook* [2] that biomedical engineering is expected to be a fast-growing occupation in the near and intermediate future. In recent years, the U.S. Department of Labor's Bureau of Labor Statistics has added standard occupational classification for "biomedical engineering" to be included in the forthcoming labor market reports and forecasts. This reflects the coming of age of biomedical engineering as a distinct discipline, and recognizes its increasing presence in the labor market. According to the U.S. Department of Labor, Bureau of Labor Statistics, Occupational Employment and Wages, 2005, industries with the highest levels of employment in biomedical engineering include scientific research and development, services, pharmaceuticals and medicine, medical equipment and supplies manufacturing, general medical and surgical hospitals, and electronic instrument manufacturing. In addition, in the same publication, the Bureau of Labor Statistics indicates that Massachusetts is among the states with the highest concentration of workers in this occupation, and is a top-paying state in

this occupation. Furthermore, the Bureau of Labor Statistics indicates that the greater Boston area is one of the top metropolitan areas in the country with the highest concentration of workers in this occupation, as well as one of the top-paying metropolitan areas for this occupation. The indications are that biomedical engineering is a lucrative career choice for students in our geographic area.

Women in engineering are more attracted to Biomedical Engineering:
In its review of the 2005 literature publications, the *Society of Women Engineers Magazine*[3] indicated the following: *"Women continue to account for a small percentage of graduates in the largest fields of engineering but they accounted for almost one-half, 45.5 percent, of graduates in the relatively new area of biomedical engineering."* Women students were expected to be a substantial constituent of the biomedical concentration program. We are in the second year of implementing this concentration, and a large proportion of our women students have gravitated toward this concentration. In addition, anecdotal information gleaned from some of the women in the freshman class leads us to infer that the biomedical systems engineering concentration has attracted new women students who normally may not have considered a career in engineering or enrolling at Wentworth.

The local competitive landscape:
Three local universities offer biomedical engineering degrees: Tufts University, Boston University, and Worcester Polytechnic Institute. A thorough analysis of the programs at these three institutions leads us to believe that a graduate from the electromechanical engineering program with a concentration in biomedical engineering will be very competitive (if not better prepared) in performing biomedical engineering work as the graduates of these neighboring institutions. The following results were obtained:

Tufts University:
Tufts University[4] offers a Bachelor of Science degree with a first major in electrical, electrical and computer, or mechanical engineering, and a second major in biomedical engineering. There is no stand-alone biomedical engineering program. A total of ten courses must be taken. No more than five of these courses can be taken to satisfy the requirements of both the first and second major.

The second major requires only one, three-hour core biomedical engineering course, "Introduction to Biomedical Engineering", at the sophomore level. The remaining courses are chosen as electives among several engineering, biomedical engineering, mathematics, science, and humanities courses. The single four-credit course of senior design required for the first major must have "an emphasis in biomedical engineering."

For comparison (as detailed later) the biomedical systems engineering concentration at Wentworth requires three four-credit courses, each five hours long, and all involving laboratory and project work, one five-hour three-credit junior design and two four-credit senior design courses. The biomedical systems engineering course includes the topics covered by Tufts' only required sophomore-level core course, but at a higher, fifth-year level. We believe that the Wentworth's biomedical systems concentration is not only competitive with Tufts' program, but

is stronger in terms of the classroom and laboratory experience in biomedical subjects provided to the students.

Boston University:
Boston University has an older and larger biomedical engineering undergraduate program. Boston University[5] requires courses of signals and systems, control systems, and an elective chosen among biomechanics and fluid mechanics. These courses have the same theoretical content as the corresponding electromechanical courses at Wentworth, with, in addition, applications in biology. The Wentworth biomedical concentration provides the same concepts by covering statics, dynamics, fluid mechanics, mechanics of materials, thermodynamics, heat transfer, control theory, signals and systems, and materials science in electromechanical engineering. Moreover, the program integrates these concepts with applications in biology and physiology in the fifth-year biomedical systems engineering as well as in the junior design and the two senior design courses. This has the advantage of providing a higher degree of integration as well as the opportunity to utilize advanced mathematics and modeling.

In addition, Boston University requires two senior design courses involving a total of eight credits, while the biomedical systems engineering concentration at Wentworth involves a total of eleven credits (one three-credit junior design and two four-credit senior design courses, all five hours long).

Finally, at Boston University, students graduate with a bachelor of science in a single discipline, biomedical engineering, while at Wentworth they will major in two disciplines as at Tufts University, though at a more integrated and a broader level.

Worcester Polytechnic Institute:
Worcester Polytechnic Institute[6] offers an accredited undergraduate program in biomedical engineering. This program, like Boston University's, suffers from being a specialized biomedical engineering program, which limits student career opportunities in other areas of engineering. In addition, only one quarter of a four-credit capstone senior design course is required and there is no co-op requirement. A total of eight courses in biomedical engineering are required. Since Worcester Polytechnic Institute operates on a quarterly system, when compared to Wentworth and other schools on the semester system, the actual number of required courses is five. Most of these courses are electives chosen freely among several biomedical engineering courses, which provides for less integration. We believed that the Wentworth program does not have these drawbacks.

In conclusion, we believe that the biomedical systems engineering concentration at Wentworth will provide a high-quality, affordable education that will be competitive with the biomedical engineering programs in Massachusetts. It offers the following advantages over these programs:

- a small-college learning environment,
- a much broader multi-disciplinary and interdisciplinary education that provides more opportunities for students,
- a broad, high-quality, rigorous interdisciplinary education in engineering, despite a lesser variety of elective courses such as those available at larger institutions like BU, Tufts, or WPI,

- more design experience than any of the Massachusetts biomedical engineering programs,
- more laboratory experience,
- a more affordable education,
- co-op experience,
- increased availability and accessibility of co-op experiences, since no other biomedical engineering program in Massachusetts requires co-op experience; this is also facilitated by Wentworth's proximity to the Longwood Medical Area.

Accreditation:
The concentration was designed so as to satisfy accreditation requirements for biomedical engineering. We have not applied for accreditation since the core Electromechanical Engineering Program is an EAC-of-ABET accredited five-year interdisciplinary electromechanical engineering program meeting simultaneously the accreditation criteria for electrical engineering and for mechanical engineering. The following are ABET Program Criteria[7] for biomedical engineering programs:

1- The structure of the curriculum must provide both breadth and depth across the range of engineering topics implied by the title of the program.

2- The program must demonstrate that graduates have: an understanding of biology and physiology, and the capability to apply advanced mathematics (including differential equations and statistics), science, and engineering to solve the problems at the interface of engineering and biology; the ability to make measurements on and interpret data from living systems, addressing the problems associated with the interaction between living and non-living materials and systems.

The curriculum for the biomedical systems engineering concentration as described below was designed so as to satisfy these requirements.

Resources:
The concentration was designed on the basis of optimally utilizing existing resources at Wentworth. The following were determined as additional required resources:

1- A Biology laboratory. This was a basic microbiology laboratory already being used in environmental engineering as a waste-water laboratory.
2- Electromechanical design laboratory. This is a laboratory used in the electromechanical engineering program.
3- A biomedical systems engineering development laboratory. This is a small laboratory used to develop and research biomedical experiments.

Two faculty members, one, Salah Badjou, a biophysicist in the electromechanical engineering program, and the other an environmental engineer with education and expertise in biology, were identified for teaching the physiology courses.

Curricular Requirements:
The curriculum may be thought of as a pyramid having as the base the electromechanical engineering program, with the electrical and mechanical parts each representing half, and a biomedical concentration as the top of the pyramid. The result is a complete holistic education integrating the broadest fields of engineering with the life sciences. Table1 presents a matrix of

the Electromechanical Engineering Curriculum showing the embedded Concentration in Biomedical Systems Engineering; the special requirements for this concentration are underlined.

Table1. Matrix of the Electromechanical Engineering Curriculum showing the embedded Concentration in Biomedical Systems Engineering; the requirements for this concentration are underlined.

First Year

Fall Semester		Lec	Lab	Cr	Spring Semester		Lec	Lab	Cr
ENGL100	English I	4	0	4	ENGL115	English II	3	0	3
MATH265	Engineering Math I	3	2	4	MATH280	Calculus I	4	0	4
CHEM100	Chemistry I	3	2	4	COMP120	Computer Science I Using C	3	2	4
ENGR100	Introduction to Engineering	2	4	4	PHYS310	Engineering Physics I	3	2	4
				16	ENGR160	Intro to Engineering Design	2	4	4
									19

Second Year

ELECTIVE	Social Science	3	0	3	ELECTIVE	Social Science	3	0	3
ELECTIVE	Physiology for Engineers I	3	2	4	MATH510	Calculus III	4	0	4
MATH290	Calculus II	4	0	4	ELEC281	Network Theory II	2	2	3
PHYS320	Engineering Physics II	3	2	4	ELEC244	Digital Systems	3	2	4
ELEC231	Network Theory I	3	2	4	MECH251	Engineering Statics	3	2	4
				19	ENGL350	Writing Competency			0
									18

Summer Semester : Cooperative Work Semester – Optional

Third Year

ELECTIVE	Physiology for Engineers II	3	2	4	MATH890	Linear Algebra & Matrix Theory	4	0	4
MATH620	Applied Differential Equations I	4	0	4	MECH565	Engineering Fluids	3	2	4
ELEC443	Analog Circuit Design	3	2	4	ELEC471	Embedded Computer Systems	2	2	3
MECH302	Mechanics of Materials	3	2	4	MECH496	Material Science	3	2	4
MECH505	Engineering Thermodynamics	3	2	4	ELMC461	3rd Year Engineering Design (must be in Biomedical Engineering)	1	4	3
				20					18

Summer Semester: Cooperative Work Semester I – Required (must be in Biomedical Engineering)

Fourth Year

MATH505	Probability & Statistics for Engineers	4	0	4	ELECTIVE	Humanities or Social Science	4	0	4
ELEC584	Engineering Signals & Systems	3	2	4	ELEC820	Feedback and Controls	3	2	4
ELEC586	Motors and Controls	3	2	4	MECH572	Engineering Dynamics	3	2	4
MECH595	Engineering Heat Transfer	3	2	4	MECH600	Advanced Mechanics of Materials	3	2	4
COMM400	Technical Communications	2	2	3	MECH620	Engineering Thermal Design	1	4	3
				19					19

Summer Semester: Cooperative Work Semester II – Required (must be in Biomedical Engineering)

Fifth Year

ELECTIVE	Humanities or Social Science	4	0	4	ELECTIVE	Humanities or Social Science	4	0	4
ELECTIVE	Biomedical Systems Engineering	3	2	4	MGMT510	Engineering Economy	3	0	3
ELMC815	Electromechanical Systems I	3	2	4	ELMC870	Electromechanical Systems II	3	2	4
ELMC831	Senior Design I (Biomedical Eng.)	1	6	4	ELMC881	Senior Design II (Biomedical Eng)	1	6	4
				16					15

Curriculum of the Biomedical Systems Engineering Concentration:

All the courses (except for electives) that were required for a B.S. in Electromechanical engineering remained the same. The electives, co-op employments and design courses were modified as follows:

i - Three biomedical engineering courses (taken as electives). Each is a four-credit course with laboratory and research projects:

1- Physiology for Engineers I: focusing on cell physiology and ecology
2- Physiology for Engineers II : focusing on human organ systems and their interactions with the environment
3- Biomedical Systems Engineering: integrating advanced electromechanical engineering with physiology

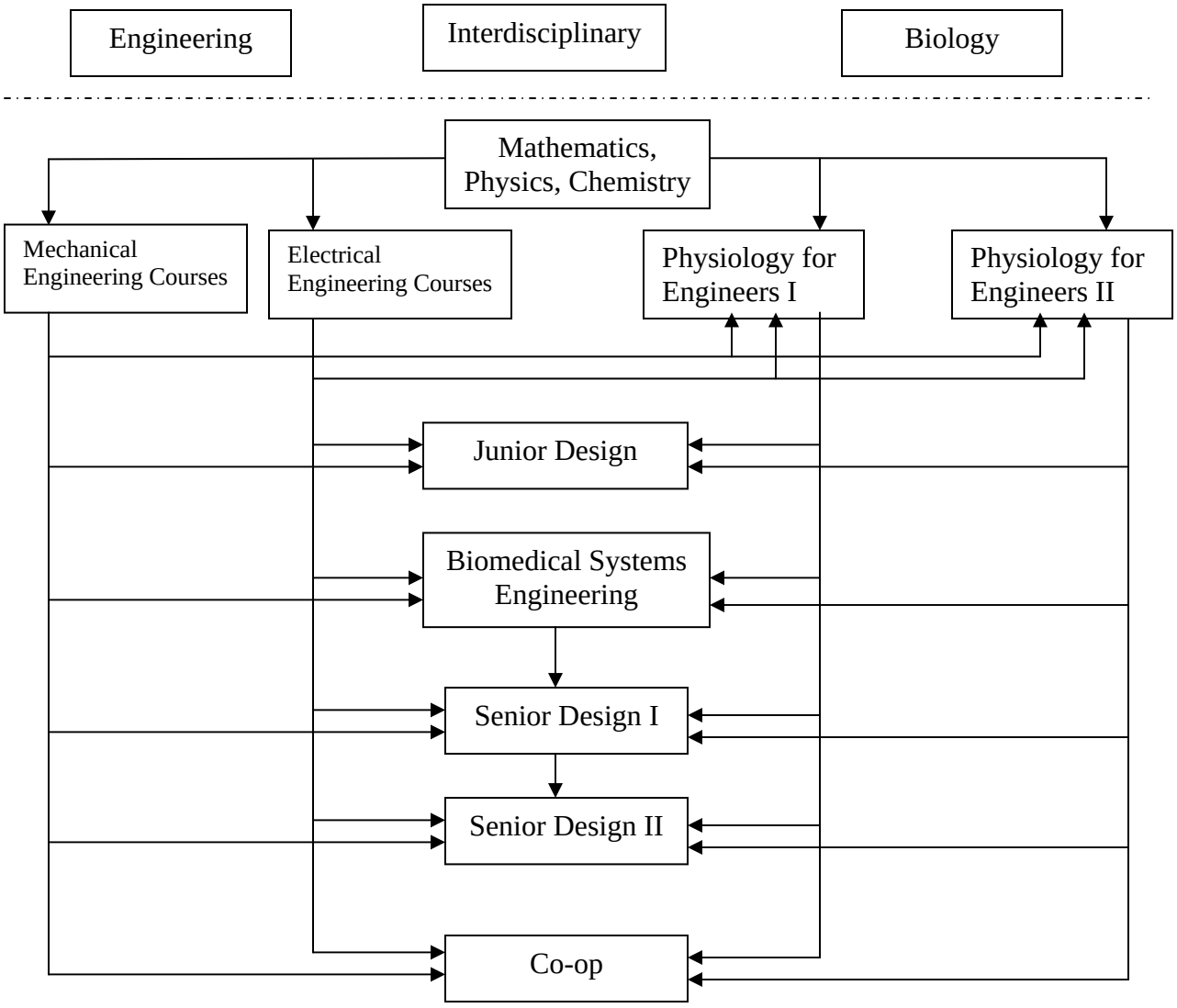
ii - Junior Design: Students enrolled in this concentration must select a biomedical engineering project in their third year design course. This project simultaneously satisfies the electrical and mechanical requirements. The sequence is such that in this design course students would be able to integrate knowledge acquired in physiology into their work.

iii - The capstone 5th-year design experience (over two semesters as Senior Design I and II) has to be in biomedical engineering. This project also simultaneously satisfies the electrical and mechanical requirements.

iv - The co-op experience/employment (over two summers) as required by the electromechanical engineering program remains the same except that the experience has to be in the biomedical engineering field. We consulted with our Co-op Office on this issue and we actively work with the Co-op Office to help place the students in biomedical engineering in companies and hospitals.

Table 2 presents a curriculum flowchart for the Biomedical Systems Engineering Concentration.

Table 2. Biomedical Systems Engineering Concentration Curriculum Flowchart



The BMES Student Club:
The first class of students who took Physiology for Engineers I in Fall 2005 simultaneously created a Wentworth Chapter of the Biomedical Engineering Society advised by one of the authors. They developed a comprehensive brochure, designed to implement the philosophy of the concentration, supplement their biomedical education, and provide an opportunity for students to actively and creatively get involved in the further development of the concentration; these measures have produced a feeling of *ownership of the program* among the students. This has generated an enormous amount of enthusiasm. Club members have enthusiastically sponsored a series of events such as a successful biomedical exhibition and a number of biomedical lectures, and have been developing a project involving microscopy and image processing. In addition, they have been tremendously helpful in recruiting additional students to the program.

Assessment:
The assessment for this concentration is still in its early stages--the concentration is only in its second year of implementation. We have identified the goals to be achieved, and performance criteria for each goal (what will the graduate be able to do?), designed and are currently implementing a robust curriculum with great breadth and depth that should help achieve the goals, and identified our assessment and data collection methods for each objective; and as time goes by we shall use the feedback data in order to make the appropriate adjustments and continuously improve the program.

During this past year, feedback from co-op employers in the biomedical engineering field has indicated a high degree of satisfaction among those employing students from this concentration. There were 11 students enrolled in Physiology for Engineers I in Fall 2005. Of these students, 10 continued with Physiology for Engineers II in Fall 2006. Physiology for Engineers I was offered for the second time in Fall 2006 with twelve students enrolled. A set of 20 comprehensive laboratory experiments was developed, and is being enhanced on the basis of ongoing student feedback.

Scaling up this experience:
The authors believe that the strategy that was used has the potential to be portable. Moreover, other concentrations of non-engineering specialties could be planned and implemented in established engineering programs in order to bestow great additional value to the newly graduated engineer. Examples of those concentrations may include business, entrepreneurship, economics, energy, art, and k-12 education. Care would have to be exercised not to dilute or weaken the existing engineering programs. A critical element for the success of scaling up this experience to other institutions or other engineering programs is to have thoughtful and committed individuals who would take ownership of designing and implementing the concentration; those individuals would have to be allowed to work free of the bureaucratic hurdles that stifle innovation and resist creative work.

Our experience shows that the unique collegial structure of the Electromechanical Engineering Faculty Committee[1] and its necessary empowerment by the top level of the administration were a crucial environment enabling the harmonious synergy of efforts by its members.

What would a typical graduate be able to do?
Typical graduates from this program shall possess the skills, knowledge and competencies to develop medical devices and procedures for diagnosis and therapy, manage medical technology effectively, support research that quantifies biomedical systems and processes, and provide indispensable technological support for life scientists who use molecules to design replacements for damaged organs or tissues. We believe that our graduates will have unique interdisciplinary abilities that make them highly competitive with other biomedical engineering graduates.

Summary:
This paper reported on the establishment of a faculty-driven, high-quality biomedical engineering specialization that was established in the form of a concentration within a well established electromechanical engineering program. The addition of the concentration required only limited additional resources. The faculty exercised care so that the addition of the new concentration did not alter or weaken the structure of the existing electromechanical engineering program but rather strengthened it, and provided greater opportunities for the graduates. The result is a high-quality program that is competitive with other biomedical engineering programs offered in Massachusetts. The authors described the uncommon context in which this concentration was established, the preparation, the market research, the competitive landscape, the resources needed, the curriculum being implemented, and assessment plan. In addition, the authors provided their thoughts and tips on duplicating this endeavor at other institutions. The authors also discussed scaling up this experience to other established engineering programs where other non-engineering subspecialties can be implemented in order to bestow great additional value to the newly graduated engineer.

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We would like to thank the Electromechanical Engineering Faculty Committee members and Associate Professor Henderson Pritchard for providing indispensable help. We would like to thank particularly Professor Frederick Driscoll and Nancy Chedid, M.D. for their invaluable input. We would also like to thank our students for giving us inspiration and for providing us with invaluable feedback.

References:
1- Internal documents about the Electromechanical Engineering Faculty Committee structure:
In summary, this eleven-member interdisciplinary and interdepartmental committee is composed of four faculty members with electrical engineering, one with physics/biophysics, four with mechanical engineering, one with interdisciplinary electrical and manufacturing engineering, one with mathematics, and one with industrial psychology background and expertise. This standing committee has worked together as a cohesive team for more than ten years, and has been responsible for designing, implementing, and overseeing a unique-in-the-nation five-year electromechanical engineering program. This program is the only one of its kind in the US that is currently accredited by EAC of ABET.

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