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# ME for EEs - Where Are All the ME Courses in the EE Curriculum?

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## Abstract

An unfortunate premise is that undergraduate Electrical Engineering (EE) programs seem to be unable to accommodate within their curricula substantive Mechanical Engineering (ME) courses. Alternatively, a single course obliquely called *ME for EEs*, a counter to the *EE for MEs* course usually required in the ME program, may be necessary. This requisite course has been vetted over three semesters, directly assessed by Course Learning Outcomes (CLO) mapped to Student Outcomes (SO) and indirectly assessed by a course survey. The impact of the course on the interdisciplinary capstone design was notable and indirectly assessed by surveys and interviews. The inclusion of such a requisite *ME for EEs* course in the typical and crowded EE program is not as endemic as may be perceived but is indispensable to the profession. Although such an *ME for EEs* course has been heralded before and is not necessarily unique, consider this another clarion call for its inclusion as a requisite course in the EE program.


## EE and ME – Together Again?

The Electrical Engineering (EE) discipline was once embellished with a significant number of Mechanical Engineering (ME) courses suitable for between-the-world-wars technical training[1]. Even as late as the 1960s EE students were required to take ME courses in statics, dynamics, materials and thermodynamics[2]. However, the rapid development of digital logic integrated circuits and the microprocessor in the 1970s shifted the extent of the EE curriculum away from these ME courses.

Accelerating the shift were new topics such as microelectronics, probability and statistics, digital signal and image processing and digital communications and control. The result is that many EE programs today do not feature any required courses in ME. The dismissive comment is now often heard that "ME topics are covered in Physics, especially statics and dynamics". This sentiment could be extended, with the same degree of irony, to "EE topics are covered in Physics, especially basic circuits and electromagnetics". Neither of these statements is quite correct when the material and the Engineering application are compared.

While the typical EE curriculum might include as many as three Engineering elective courses, the advising suggestion that may predominate is to choose only courses from the EE discipline. This is especially prevalent when preparatory courses are considered within the ME program. Although the prerequisites for an initial ME course in statics would be satisfied, an interdisciplinary course of study in ME could utilize all the remaining Engineering electives and may not be reasonable. Furthermore, although substantive, a single course in statics, often the elective or requisite alternative, does not provide any breath of understanding of the ME discipline.

The relationship of the subdisciplines of EE and ME in electromechanics and energy and power in course work must go beyond the proverbial *pressure is voltage*, *flow is current* analogy. Since ME students, generally, are still required to take a single *EE for MEs* course and laboratory, often provided by an electrical systems service course from the ECE department, the analogy can be infused into ME courses quite naturally.

The typical *EE for MEs* course is supported by a comprehensive text with topics that span resistive and reactive electric circuits, AC power, semiconductor and power electronics, electric machines, digital logic and instrumentation[3]. The usually corequisite laboratory provides an experience garnered from several EE laboratories for the ME student. Obviously the ME curriculum still considers that a modicum of understanding of the breath of the EE profession is required for its profession and practice. Why is it that a different opinion seems to be prevalent for the EE curriculum?

Unfortunately, the reverse, the *ME for EEs* course in the EE curriculum, is not endemic and infusing mechanics into such EE courses as electromechnical systems, control theory and electrical power and energy conversion remains challenging. Although some EE programs have recognized this curricular deficit and have engaged their ME department colleagues to provide a service course, such a course has been only sporadically provided and often not required. A survey of peer institutions, using the predicate that the single *ME for EEs* course be a comprehensive upper division offering, has found that only 18 of 94 (19%) EE programs have either an elective (14) or requisite (4) course.

Although the *ME for EEs* course is therefore not necessarily unique, consider this then as a clarion call for a widespread requisite course in mechanical systems for EE students. Undergraduate EE students without such an *ME for EEs* course remain at a distinct disadvantage in focused areas of employment such as electromechanical systems and energy and power. Research in Engineering education has also identified perhaps the key barrier to interdisciplinary practice[4]. Students apparently lack the ability to provide the salient connections between and understanding of the contributions of various disciplines. This should be a further concern to EE educators and would be ameliorated by the adoption of an *ME for EEs* course.

## Getting It Moving

The *ME for EEs* course concepts to be covered were endorsed by the Industrial Advisory Committee (IAC) in recognition of the paucity of understanding afforded by the single requisite course in statics formerly required in the Electrical concentration of the EE program at our institution. The IAC was adamant in rejecting the removal of the requisite course in statics and its replacement by an additional EE technical elective. The IAC has continued to view the inclusion of the *ME for EEs* course as a hallmark of this aspect of the EE program for professional practice opportunities in interdisciplinary EE and ME.

The suggested *ME for EEs* course includes modules on statics, dynamics, strength of materials and an introduction to fluid mechanics and thermodynamics. The breath of the material here is certainly no more than that provided by the *EE for MEs* course. However, selection of a suitable course text is somewhat problematic and is certainly a reflection of the scarcity of this course offering in EE programs. If such an *ME for EEs* course was widely required in the EE program, then the number of suitable texts available would certainly be seen to be greater.

Some of the available texts that span the material are intended for an introductory course for ME students in their first or second year and have sections on the profession, the design process, standards and technical communication[5]. These texts also often have a minimal requirement for prerequisite calculus and physics. There are texts used for upper division ME courses but several would be necessary to provide the material envisioned for the *ME for EEs* course[6, 7, 8].

There seems to be only a few available texts that are seemingly more reasonable for upper division EE students. The text chosen is a combined offering in statics and dynamics with an introduction to fluid mechanics and thermodyanmics[9] which is supplemented with reference materials and projects appropriate for the EE profession.

The suggested *ME for EEs* course is then offered in the third year with prerequisites of calculus and physics and utilize *what-if* analyses in MATLAB and mechanical models in SimMechanics for projects. This requisite *ME for EEs* course provide immediate support for following courses in electromechanical and energy conversion systems in the EE program and would not certainly be pedestrian in nature.

**ME for EEs: Mechanical Systems**

Such an *ME for EEs* course (ENGR3334 Mechanical Systems) has been developed, presented, and assessed by direct and indirect methods for three semesters and contributes to the continuous improvement of the EE program. The *ME for EEs* course replaced a requisite three semester hour course in statics without a laboratory in the Electrical concentration in our EE program. The course topics and projects in MATLAB, Simulink and SimMechanics provide a reasonable *hands-on* experience that is directly extended in the course on digital control and the capstone senior design project.

The *ME for EEs* course topics and the direct Engineering applications certainly counter the ironic sentiment that “ME topics are covered in Physics, especially statics and dynamics”. The course syllabus considers the following modules:

> *Statics:*
>
> Tensile, compressive and shear force, stress, strain, Hooke’s law, modulus of rigidity, tensile testing, proof stress
>
> Center of gravity, equilibrium, resolution of forces, supported beams
>
> Joints and sections, bending moment, shearing force, uniformly distributed loads
>
> Centroids, first and second moments of simple and regular sections, bending of beams, torque, twisting of shafts
>
> *Dynamics:*
>
> Linear and angular velocity and acceleration, linear momentum and impulse, centripetal acceleration, moment of inertia

Coefficient of friction, friction of an inclined plane, simple harmonic motion, simple and compound pendulum

Torsional vibrations, force ratio, pulleys, screw-jacks, gear trains, levers

*Thermodynamics*:

Specific heat capacity, conduction, convection, radiation

Thermal expansion, coefficient of linear, superficial and volumetric expansion

*Fluid Mechanics:*

Hydrostatics, fluid, atmospheric and Archimedes principle, absolute and gauge pressure, buoyancy

Fluid flow, flowmeters, anemometer, equation of continuity, flow nozzle, turbine, Bernouli's equation

*Projects:*

Course projects in mechanical models with MATLAB, Simulink and SimMechanics

**But Does It Work?**

The impact of the *ME for EEs* course was assessed by student grade performance on examination problems categorized by the Course Learning Outcomes (CLO) for the three semesters since its inception. The student performance on the CLOs is a cohort longitudinal study of cognitive learning demonstrated by knowledge recall and intellectual skills[10]. CLOs have also been used in this manner for assessment, evaluation and continuous improvement across an undergraduate Engineering program[11]. A collection of several CLOs represent the essence of the material in the course.

The course CLOs are mapped to Student Outcomes (SO) as part of outcome based learning. The results were considered in the Academic Evaluation, Feedback and Intervention System (AEFIS) used for all Engineering courses in the College to provide continuous improvement. A single CLO is a definitive statement that can be readily mapped to specific topics of the course material and thus to problems derived from those concepts.

Here is the catalog description, CLOs and SOs for this *ME for EEs* course:

*ENGR3334 Mechanical Systems* - This course considers the fundamentals of mechanics including statics, dynamics, materials, thermodynamics and fluid mechanics and their application to systems of beams, pulleys, gear trains, levers exhibiting vibration, heat conduction, convection and expansion and fluid flow.

Course Learning Objectives

1. Understand and apply the principles of statics in mechanics (SO A, E, K)

2. Understand and apply the principles of dynamics in mechanics (SO A, E, K)
3. Understand and apply the fundamentals of thermodynamics (SO A, E, K)
4. Understand and apply the fundamentals of fluid mechanics (SO A, E, K)

Course Topics

1. Tensile, compressive and shear force, stress and strain (CLO 1)
2. Bending of beams, twisting of shafts and torque (CLO 1)
3. Linear momentum and impulse, moment of inertia of compound shapes (CLO 2)
4. Coefficient of friction, screw manipulators (CLO1, 2)
5. Simple and compound pendulums, torsional vibrations (CLO 1, 2)
6. Pulleys, gears and levels in electromechanical systems (CLO 1, 2)
7. Specific heat, thermal expansion, cooling of electronics (CLO 3)
8. Hydrostatics, fluid flow, fluidic control (CLO 4)

Student Outcomes

A. An ability to apply knowledge of mathematics, science and Engineering
E. An ability to identify, formulate, and solve Engineering problems
K. An ability to use the techniques, skills, and modern Engineering tools necessary for Engineering practice.

The change in the performance on examination problems categorized by the CLOs during the study is listed in the Table 1 for each semester. The unpaired t-test is used to determine the statistical significance ($p < 0.01$) of the difference between the first course offering in Fall 2013 and the most recent in Fall 2015 which indicates an overall improvement in performance. Although comparisons made to the first course offering may be somewhat specious, the material presented in the course has been augmented with additional problems and projects relevant to EE professional practice.

| ENGR3334 Mechanical Systems | | | | |
|---|---|---|---|---|
| CLO | Fall 2013<br>n = 26 | Fall 2014<br>n = 31 | Fall 2015<br>n = 35 | Fall 2013 to<br>Fall 2015 |
| 1 | 78.1 ± 8.2 | 84.2 ± 7.4 | 83.8 ± 3.8 | $p < 0.0006$ |
| 2 | 75.5 ± 7.3 | 81.2 ± 6.8 | 80.9 ± 4.5 | $p < 0.0007$ |
| 3 | 72.9 ± 6.6 | 78.1 ± 6.9 | 84.1 ± 5.1 | $p < 0.0001$ |
| 4 | 74.8 ± 7.1 | 85.9 ± 3.6 | 82.9 ± 4.9 | $p < 0.0001$ |

Table 1. Mean ± standard deviation of the grades on examination problems categorized by Course Learning Objectives (CLO)

The improvement in performance was evident in all of the instances listed in Table 1. Although statistically significant, the relative mean improvement in performance for CLO 1 – statics and CLO 2 – dynamics is attributed to an adequate preparation of the students in Physics for this ME material. However, marked improvements were observed for CLO 3 – thermodynamics and CLO

4 – fluid mechanics as the *ME for EEs* course offerings were continuously improved with Simulink simulations and relevant analyses in electromechanical energy conversion and the thermal cooling of semiconductor devices.

**Surveys and Interviews**

End of semester surveys provide an indirect assessment of the efficacy and contribution of the *ME for EEs* course to the EE program. This feedback has also been used to gauge the presumed importance of ME in EE as a curricular concern of the student. The consistent survey questions from the three semesters are listed in Table 2.

The average survey results from each of these three course offerings were similar and the overall average of 88 respondents is listed in Table 2. The suggested responses were numbered from 1 - Strongly Disagree, 2 - Disagree, 3 – Neutral, 4 – Agree and 5 – Strongly Agree.

| | |
|---|---|
| This course demonstrated to me that the basic concepts in mechanics from Physics need to be explored further for my Engineering practice. | 4.8 |
| I understand that mechanical stress and strain is a fundamental concern in my Engineering practice. | 4.6 |
| I can envision that dynamics is important concept in electromechanics in my Engineering practice. | 4.4 |
| I have no interest in an Engineering practice that involves the application of mechanics, thermodynamics and fluid mechanics. | 2.9 |
| I recognize that Electrical Engineering practice could require an understanding of the principles of Mechanical Engineering. | 3.9 |
| I do not envision that hydrostatics and in application in fluidic control is an important aspect of Electrical Engineering practice. | 4.8 |
| I believe that my professional practice can integrate Electrical Engineering and Mechanical Engineering. | 4.6 |
| This course should not be a requirement for the Electrical Engineering curriculum. | 2.2 |
| I recognize that thermodynamics and the application in thermal stress is an important aspect of Electrical Engineering practice. | 4.5 |

Table 2. Survey questions for the *ME for EEs* course.

The survey results indicate recognition of the importance of the *ME for EEs* course except, and notably, for the fundamentals of fluid mechanics as presented by hydrostatics and applications in fluidic control. This final and singular course topic is only a small portion of the material but seems to be of peripheral interest to the students. However, the inclusion was supported by the Industrial Advisory Committee (IAC) as more representative of the scope of an *ME for EEs* course.

Conversely, the topic of thermodynamics and the thermal stress of electrical apparatus and electronic devices were recognized as important by the students. This course topic again was only a small portion of the material as the *ME for EEs* course emphasizes applications in electromechanical devices.

An indirect assessment of the *ME for EEs* course more notably has been by surveys and interviews of the students at the conclusion of the capstone design course and upon graduation. Faculty advisers of capstone design teams consisting of either all EE students or both EE and ME students with an electromechanical design have also been asked to provide feedback on the efficacy of the *ME for EEs* course. As a direct assessment here is somewhat problematic, this feedback has been used to gauge the contribution of the *ME for EEs* course to the EE Program.

The capstone design course CLO 3 – provide experience working as a member of an Engineering team including Engineers from several disciplines supports SO D – an ability to function on multidisciplinary teams. This CLO 3 has been noted to have been improved in those design projects involving electromechanical design where EE students had taken the *ME for EEs* course. However, this assessment is subjective as only two cadres of such EE students have had the capstone design experience.

However, and more to the point, the positive impact of the requisite *ME for EEs* course has been observed by the improvement in the CLO performance in the following EE courses in electromechanical systems and electrical power and energy conversion. These courses can now rely upon the salient competency provided by the *ME for EEs* course to the overall enhancement of those courses and the EE program.

The efficacy of the requisite *ME for EEs* course is currently being evaluated. The direct assessment results in the following courses though are very encouraging in comparison to those that utilized only Physics and a single requisite course in statics in the previous Electrical concentration of the EE program in our institution. However, if the *ME for EEs* course was not requisite then the impact on the CLO performance in the following courses would be specious.

**So Many Courses, So Little Time**

The requisite inclusion of an *ME for EEs* course in the typical EE program is fraught with difficulties. A limit on the total credit hours in a baccalaureate program implies that "if something goes in, something goes out". This same argument is made when faculty consider any requisite course for inclusion in an EE program, such as electromagnetics, rather than to "make room" for additional EE technical electives.

Why is it then that ME programs nearly without question include an *EE for MEs* course in their crowded undergraduate curriculum? The inclusion of a minor in EE for ME students has also been touted for interdisciplinary Engineering education[12]. Do ME programs consider a modicum of interdisciplinary study to be useful? Should EE programs not do so? Clarion calls for such an *EE for MEs* course, either requisite or elective, have been made before. Why have they been ignored?

The requisite inclusion of such an *ME for EEs* course in an EE program is supported by the difficulties incurred in the implementation of following courses in energy conversion and electromechanical control systems[13, 14]. However, such a requisite may not be appropriate for all EE programs.

The EE program at our institution has three academic concentrations: Electrical, Computer and Bioelectrical Engineering. The *ME for EEs* course is only requisite in the Electrical concentration in our EE program where it has replaced the prior requisite course in statics which the faculty was considering to remove. In this case “nothing went out” but the support of a diverse and concerned Industrial Advisory Committee for this interdisciplinary curricular improvement is gratifying.

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