AC 2010-2356: MODERN MATHEMATICS REQUIREMENTS IN A DEVELOPING ENGINEERING PROGRAM

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Abstract

This project is a collaboration of math and engineering educators ___, meant to closely analyze the educational relationship between math and engineering as part of the development of a new innovative electrical and computer engineering program. The main objective is to optimize the curriculum for efficiency in educating engineers with skill sets that allow them to compete effectively in the global economy and to pursue successful careers.

Mathematics education in engineering curricula has undergone very little progress within the past century, while the field of engineering and the educational demands of the engineering workforce have changed quite significantly. Much effort is needed in improving the mathematics content to provide closer correspondence with and support of engineering education. One particular aspect of modernization is increased integration of powerful and widely available computing tools in education. New technologies have rendered many topics still taught in mathematics somewhat obsolete while bringing to the forefront the need and ability to teach different areas of mathematics in increased depth. This article discusses several issues related to mathematics education for engineers.

I. Introduction

The design of a new curriculum has led to the analysis of several related issues. Of particular importance is the preparation in mathematics of engineering students and the creation of course work in mathematics that better serves the needs of a sound and effective modern education for today's students.

The need to reform engineering education, particularly the mathematics content, stems from several pressing issues. In recent years, close attention has been given to the desired characteristics of engineering graduates and to their skill sets, leading to new accreditation requirements from the Accreditation Board for Engineering and Technology (ABET). Within all engineering disciplines, a broad education in the arts, humanities, and the sciences is deemed necessary, along with sufficient engineering training. This has led to increased curriculum overcrowding and there is danger that students may be insufficiently prepared in their main career choice area of engineering. In fact, the ability to complete an undergraduate degree in engineering within four years is now restricted only to the most hard-working and motivated of students and even so it is only possible by taking extra summer or winter courses where available.

The technical difficulty associated with engineering greatly restricts the number of qualified high school graduates who want and are able to undertake engineering studies. In the United States, about 5% of all bachelor's degrees are in engineering compared to Asia, where 20% are in engineering, and the percentage exceeds 10% in many other countries worldwide[1]. First university engineering degrees in the US have decreased compared to 1985. At the same time, there has been a significant increase in engineering degrees in other countries. Analyses of test results show that only a small percentage of students have math and science skills at or above the proficiency required for engineering study[2]. Given these issues, curricula in general and engineering curricula in particular must be examined from a new and dynamic perspective[3]. Typically, freshman engineering students are challenged by more complex material delivered at a faster rate than what they experienced in high school. In general, weak pre-college problem solving skills and inadequate study habits[4] hinder the success of students in engineering classes. Therefore, one of the biggest challenges in engineering education is freshmen's low proficiency in mathematics[5]. In response to the increasing need to broaden and increase math proficiency for engineering students, it has been proposed that a 2-3 years extension of engineering education beyond undergraduate studies offers the chance of reaching adequate math and engineering goals[6]. However, it is clear that adding more mathematics content without increasing the required study period is impractical due to already overcrowded curricula and the need to teach constantly improving and increasing engineering material. The solution therefore lies in improving the mathematics courses already present in the curriculum in terms of usefulness and relevance to the engineering discipline. This requires a thorough review of all required math courses, on a topic-by-topic basis, to identify essential and useful material while eliminating content of lesser relevance. In some instances it may be beneficial to integrate mathematics content within engineering courses. A few engineering institutions have reported math and engineering curriculum integrations[7-11] that led to superior student preparation, although some associated difficulties have also been reported[9].

Modern educators and students have at their disposal far more powerful computing, analysis, and simulation tools than their predecessors. These tools are used to some limited extent already but they can be integrated in modern courses to greatly improve course content and to facilitate learning. These same tools may also be used to modify mathematics education in order to emphasize deeper understanding of important concepts and to pursue efficient teaching avenues that encourage and improve critical thinking.

A sensible conclusion to this discussion is that US universities must strive to improve the quality and efficiency of engineering education to produce qualified engineers for the global workforce. The activity described in this paper is an attempt in this direction by streamlining and optimizing the symbiotic educational relationship between mathematics and engineering.

II. Mathematics in a Crowded Curriculum

An engineering curriculum must support its degree program objectives, satisfy all accreditation requirements, and ensure successful professional engineering careers for its graduates. In order to satisfy these conditions, engineering schools have established curricula that include sets of courses in each of the four categories illustrated in Figure 2.

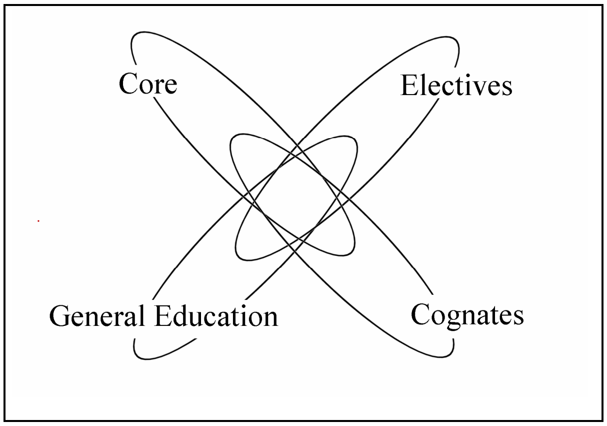

Figure 2. Components of a modern curriculum

This diagram illustrates the existing overlap between the four main components of a general curriculum that together constitute a complete degree program:

1. General education requirements – these courses provide a broad college education in the arts, humanities, social sciences, natural sciences, mathematics, and computer science.
2. Cognates – these are the courses in areas that provide essential preparation for the study of engineering. These consist of courses in mathematics, chemistry, biology, physics, and computer science.
3. Core – Core courses in engineering provide the education and training needed for the professional practice of engineering.
4. Electives – These are typically choice courses mostly in engineering or the cognate subjects that allow students to acquire deeper knowledge in a particular subject area.

In many instances, the number of courses required for a degree program is limited by state regulations (to around 120 semester credit hours), financial aid requirements, university rules, or other constraints and an engineering degree is supposed to be achievable in four years of full-time study, or eight semesters. US universities must work within these constraints to produce an engineering workforce able to compete in a global market with graduates of foreign schools that are not subject to the same constraints and time limits. In fact many countries offer only five-year or more engineering degrees.

III. Traditional and Modern Mathematics Preparation

For several decades, in many engineering schools the backbone of mathematics training has consisted of three calculus courses followed by a course on differential equations. An undergraduate catalog will contain typical descriptions of these courses along the following lines:

Calculus 1: An introduction to the differential calculus of functions of one real variable, including limits, continuity, indeterminate forms, derivatives, and their applications to curve sketching and optimization problems with a brief introduction to integral calculus.

Calculus 2: A discussion of transcendental functions, methods and applications of integration, improper integrals, sequences, infinite series, Taylor series, numerical methods, and differential

equations.
Calculus 3: Calculus of real-valued functions of two and three variables. Topics covered include: polar coordinates, curves and surfaces in space, partial derivatives and multiple integration.
Differential Equations: First order differential equations in one independent variable; constructive existence and uniqueness proofs, solutions containing parameters, extension to higher order differential equations, vector spaces and systems of linear differential equations.

While the main topics of these four courses are essential to an engineering education, much of the time is spent covering subtopics such as proofs of theorems, computation methods, and applications that have very little relevance to an engineering education while other far more important topics are left out of the curriculum. Can these four courses be replaced by a more effective sequence of only three courses dedicated to mathematics content of close relevance to engineering and engineering applications?

Additional math preparation is typically left to the student, upon recommendation from academic advisors for topics such as linear algebra, numerical analysis, vector calculus, or complex analysis. Discrete mathematics and applied statistics have recently gained in importance due mostly to the ABET 2000 accreditation requirements.

Figure 1 contrasts traditional required math courses with additional math courses widely recognized as needed in a modern electrical and computer engineering curriculum. Many schools still follow the traditional math curriculum with some other required coursework or integration of needed mathematics into engineering courses.

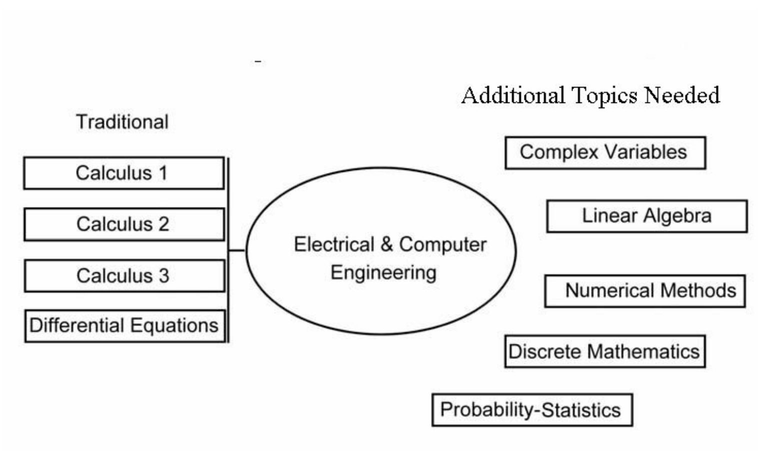

Figure 1: Math requirements in an Electrical and Computer Engineering Curriculum

To illustrate current transitions in mathematics content across engineering schools, the required mathematics courses in the curriculum of two well-known and well-reputed engineering schools are given in Table 1 where the number of course credits is converted and expressed in semester hours. The Franklin W. Olin College of Engineering in Needham, Massachusetts is an example of a recently developed engineering school that has established a creative curriculum[12] with heavily modified mathematics content among other revisions. However, most engineering schools in the nation still adhere to the traditional series of three calculus courses and differential equations with possibly other math topics added as required or elective courses in increasingly heavy curricula. Rose Hulman Institute of Technology follows a more traditional curriculum[13].

Tabel 1: Example differences in Math requirements in two engineering schools

Rose-Hulman Institute of Technology			**Franklin W. Olin College**	
Course Title	*Credits*		*Course Title*	*Credits*
Calculus 1	3.3		Calculus	Math 2
Calculus 2	3.3		Vector Calculus	Math 2
Calculus 3	3.3		Linear Algebra	Math 2
Diff. Eq. & Matrix Algebra	5.3		Probability/Statistics	Math 2
Probability/Statistics	2.7		Differential Equations	Math 2
			Discrete Mathematics	Math 2
Total Credits	18		Total Credits	12

IV. Avenues for Modernizing Mathematics in Engineering Education

Any attempt at modernizing a curriculum should be based on sound analysis of the needs of the engineering profession and on the applicability of the covered materials. With curriculum overcrowding, engineers should no longer be taught mathematics as if they were mathematicians[14], as attractive as the concept may be. One major concern must be related to the math knowledge that future engineers *can* and most likely *will* use[15].
The review and integration of math and engineering are to be conducted not only for freshman courses but for the whole range of electrical engineering courses within a unitary structure. There is a considerable mismatch between traditional mathematics content for engineering and the actual mathematics education needs of engineers within the development of a new engineering program, a point that is well expressed in the following quote[6]:
"*Clearly the engineering curriculum needs a major overhaul. To some degree, this will require modernizing the approaches to science and mathematics instruction, e.g., recognizing that discrete rather than continuous mathematics is the foundation of the digital age, … and new scientific concepts and tools have made obsolete much of the traditional curriculum.*"

Most engineering students lack adequate mathematics skills for engineering studies, one of the reasons being that engineering subjects and concepts require math preparation different from what students typically receive even as they complete their established educational requirements and pass all their math prerequisites. Such an imbalance between topics taught and topics needed greatly hinders student learning and complicates engineering education.

A glaring example of an important topic left out of the traditional math preparation is that of complex numbers, arithmetic, and conversions. Yet, one of the first core courses in electrical engineering, typically a fundamentals of electric circuits course, introduces students to the concept of *phasors* to represent voltages and currents in circuits powered with an alternating power source. Phasors are complex numbers represented in polar form and must be manipulated using complex arithmetic. ECE students must also learn and understand Fourier series, the

Fourier transform, the Laplace transform, and transfer functions in many of their courses, from signals and circuits to communication systems, digital signal processing, and control theory. All these concepts rely on complex numbers and their representations, complex arithmetic, and functions of complex variables, topics that are not sufficiently covered in the math requirements of traditional engineering curricula.

In several courses, electrical engineering students rely on matrix theory and vector calculus, both not covered in their math pre-requisites. However, much time is spent in the calculus series covering topics that bear little relation with, and are never used within, the undergraduate engineering curriculum. Examples include several mathematical techniques for derivative and the integral, area, and volume computation and coverage of various mathematical proofing methods that are usually quickly forgotten by students and never seen again in engineering.

ABET accreditation now requires that students satisfy certain outcomes, including engineering applications of statistics and discrete mathematics, two areas that are not adequately covered by the traditional math requisites. Other mathematics topics needed but not covered in engineering include probability and statistics, linear algebra, vector calculus, and numerical analysis. Figure 2 illustrates the traditional organization of math requisites along with other math topics needed for a modern engineering curriculum.

Integration of Modern Computing Tools

There are two aspects to mathematics education: conceptual and computational. In recent years and particularly since the early 1980s, several important advances in computing, design, simulation and analysis tools that directly impact engineering and mathematics education have been made. High performance hand-held calculators capable of advanced numeric and symbolic computation and graphing are now available and accessible to all students at very affordable prices. Personal computers are now part of many classrooms and are made available to students in every higher education institution in the nation. The content of a student backpack now includes student-owned portable computers and several universities are now requiring personal computers from their students.

On the software side, dedicated mathematical packages such as Matlab, MathCad, Maple, and Mathematica that provide enormous computing power for engineering education are now available. In addition, commonly available spreadsheet programs are also capable of complex mathematical and statistical computations. These new tools can be more widely embraced and used to reduce and alleviate coverage of several mathematical computing techniques while facilitating learning of conceptual topics.

The internet represents a source of several dedicated programs for computing, simulation, design, graphics, visualization, and other resources, along with well-developed and illustrated tutorials[16].

These and other modern tools have been embraced and integrated in many engineering courses, especially at the graduate level, but their use in the traditional math support courses for engineers remains very limited. Many educators ponder the best way to integrate these modern computing tools and some see them as a threat to mathematics education because they prevent students from learning important computation mechanisms. Others feel that education should embrace and integrate computing tools and use them to relieve students from tedious computation algorithms and allow them to concentrate on abstract and conceptual thinking. In terms of optimizing student preparation in mathematics for engineering, modern tools offer the possibility of concentrating on conceptual mathematics and reducing the coverage of computational methods. It can be argued, as one example, that it is far more important for an engineer to know how and when to use the derivative of a function obtained from a calculator, than to be able to compute the derivative without the help of a calculator. A recently held panel discussion[17] that involved several engineering and mathematics educators indicates that this is a topic that does not meet unanimous agreement, although it deserves close attention within the modernization of the engineering curriculum.

Embedding mathematics content within engineering courses

Much of the engineering curriculum is traditionally partitioned in courses that each cover a small portion of the entire body of knowledge and training students receive. Many students fail to grasp the fact that the acquired knowledge is actually more than the sum of its courses and that their degree provides them with a cohesive and complete education. Multidisciplinary teaching helps provide students with an understanding of the relationship between all different subjects they are required to learn and demonstrates the symbiotic relation that exists between all these different courses. The relationship between mathematics and engineering is indeed very close. The integration of math education within engineering courses is one possible option for improving the overall engineering curriculum. Many instances can be found where integrating mathematics content within engineering courses can greatly facilitate learning. An example is coverage of complex functions and variables within an introductory electric circuits or a signals and systems course where complex numbers play a very important role.

Proposed Curriculum Modifications

Based on the discussions and justifications of the previous sections, the mathematics preparation course sequence considered for the new ECE curriculum under development includes:

1. Basic Calculus. Two 4-credit semester courses on the properties and applications of single-valued functions of a single variable. These two courses cover limits, differentiation, curves, graphing, integrals, and series.
2. Vector Calculus. A 4-credit semester course on multi-valued functions of one or more variables.
3. Engineering Mathematics 1. A 4-credit semester course on modeling with differential equations (25%), vector and matrix methods and applications (25%), numerical methods (25%), complex functions of complex variables (25%).
4. Engineering Mathematics 2. A 3-credit semester course on statistics and statistical methods in engineering (55%) and discrete mathematics (45%).

This list of courses is composed of 15 semester credit-hours and is believed to be achievable by reducing coverage of computational methods with increased reliance on computing tools and eliminating several topics of little relevance to ECE studies in calculus and other courses. Math preparation, in all required topics, is also supported and reinforced by reviews and applications embedded in several engineering courses. Complex numbers, for example, are also presented and reviewed within the first circuit course before being applied to phasor representation of AC signals.

This list of mathematics preparation courses has the advantage of preparing students with all the mathematics knowledge needed in a modern engineering education. Another advantage over the traditional approach to mathematics is that all of ABET's requirements in math preparation for Electrical and Computer Engineering[18] are covered. In essence, ABET insists that graduates acquire knowledge of mathematics through differential and integral calculus including differential equations, linear algebra, complex variables and discrete mathematics as well as knowledge of probability and statistics.

V. Conclusion

This article discusses the modernization of lower and upper division mathematics courses within an electrical and computer engineering curriculum under development. The justifications for reform are presented and discussed and a few initiatives for reform are proposed.
Among the proposals for reform discussed in this article are:

- a review of math content with the objective of increased content of close relevance to engineering;
- The development of a curriculum that covers complex functions and variables, calculus (including vector calculus), differential equations, linear algebra, discrete mathematics, statistics, and some elements of numerical analysis;
- Strategically embedding coverage and/or review of mathematics topics within engineering courses to ensure adequate understanding and learning;
- Develop math courses that embrace and utilize modern computing tools to concentrate on conceptual knowledge, abstract problem solving, and practical computer-aided solution finding.

A sound engineering education rests on a solid base in mathematics and many argue that engineers should be taught more mathematics rather than less. The challenge presented and discussed here is not to teach less mathematics to engineers but to teach better and more useful mathematics to improve their engineering education

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