AC 2008-2167: A NEW LOOK AT UPPER-LEVEL MATHEMATICS NEEDS IN ENGINEERING COURSES AT UAB

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NEW LOOK AT UPPER-LEVEL MATHEMATICS NEEDS IN ENGINEERING COURSES AT THE UNIVERSITY OF ALABAMA AT BIRMINGHAM

Abstract

A four semester-hour course is being designed to follow Calculus II, with the intention of replacing Calculus III and Differential Equations in the engineering curricula at the University of Alabama at Birmingham. As part of the planning process, instructors of all courses with Calculus III or Differential Equations as direct or indirect prerequisites were interviewed to (1) determine their views of the current preparation of students, (2) identify the mathematics skills that were expected of students in their courses, and (3) discuss the possibility of introducing mathematics topics using engineering problems and incorporating both problem-based and active learning techniques. Faculty were very satisfied with the capabilities of the better students to carry out symbolic manipulations of common problems, particularly if the student had recently completed upper-level mathematics courses. However, most students were very poor at applying the mathematics in their engineering courses. There was strong support for a change from teaching mathematical methods in relative isolation to teaching mathematical methods in context. The process that will be adopted involves starting with an engineering problem, including a brief discussion of cause and effect, variables, units, boundary conditions and governing principles. This preamble will be followed by teaching the mathematical tools needed to solve the problem and applying these tools to similar engineering problems. Identifying the requisite mathematical skills required a balance among designing a coherent course, meeting the many needs of the engineering programs, and being able to adequately address the topics in a four semester-hour course using active and problem-based learning. Engineering faculty enthusiastically accepted the trade off of teaching some advanced mathematical methods within their courses in exchange for receiving students with a sound, broad-based foundation and an ability to use mathematics to solve engineering problems. Areas that were deemed critical by most engineering programs were First-Order ODEs; Second-Order Linear ODEs; Vector Differential Calculus: Grad, Div, Curl; Vector Integral Calculus, and an introduction to Partial Differential Equations. The initial offering of this course will be Fall 2008.

Introduction

The engineering profession increasingly expects graduates to be immediately productive with well-developed problem-solving, teamwork and communication skills, and to demonstrate an ability to adapt to changing technologies and constraints[1]. Ted Kennedy, a founder of BE&K, a major engineering, construction corporation, emphasized the importance of these same problem solving skills during his keynote address to the Engineering Council of Birmingham in 2007. He stressed the importance of learning mathematics in an engineering context rather than in isolation, stating that applying mathematics to solve complex engineering problems is an essential, and often missing, skill for young engineers. These same expectations are reflected in the engineering accreditation process which seeks to place engineering problem-solving and design earlier in curricula. Consequently, students must apply their mathematics and basic science skills sooner within the framework of solving engineering problems.

Within the broad context, the instruction, content , and focus of the calculus and differential equations courses at the University of University of Alabama at Birmingham (UAB) have been examined critically by a committee composed of faculty from the Department of Mathematics and the School of Engineering, with the goals of enhancing student retention and improving mathematics skills in upper-level engineering courses. The university charge to the committee included:

- Establish what engineering students need to understand in order to be able to use mathematics in engineering;
- Develop an innovative 200-level course that meets the needs of engineering students;
- Ensure that problems related to engineering are emphasized

The current manuscript will discuss the process and design of a four semester credit hour course that will include the key elements of multivariable calculus and differential equations with the prerequisites of traditional MA 125: Calculus I and MA 126: Calculus II courses.

Needs of Engineering Students – Faculty Interviews

The authors interviewed faculty from Biomedical Engineering, Electrical and Computer Engineering and Mechanical Engineering who taught any course(s) that had/have either MA 227: Calculus III or MA 252: Introduction to Differential Equations as a prerequisite or had one of these courses as an indirect prerequisite, i.e., a prerequisite or corequisite of a prerequisite. (Civil, Construction, and Environmental Engineering and Materials Engineering do not have any required courses that met these criteria.)

Prior to these discussions, a diagram of the proposed concept of a problem-based learning approach to a course was prepared by the authors, Figure 1. All topical areas would start with an important engineering problem to be introduced by a faculty member from one of the five departments. Units would be emphasized throughout, and the wider applications of mathematical tools would be discussed. For example, the design of a shock absorber/spring system from vehicle dynamics is an excellent introduction to Forced Oscillations and Resonance, which is an application of Second-Order Linear ODEs. This preamble will be followed by teaching the mathematical tools needed to solve the problem and applying these tools to similar engineering problems. The starting point of any topic will be an engineering problem, rather than a mathematical technique.

There were twelve interview sessions with a total of 17 faculty which primarily addressed three issues:

1. How effective are the current calculus and differential equations courses in preparing students for your course(s)?
2. Do you believe that a change in approach that utilized the methodology given below in Figure 1 would help?

3. What topics in these courses are critical to student learning in your course(s)? Are there topics that would also be beneficial? Faculty were cautioned that all of the topics currently addressed on the syllabi of MA 227 and MA 252 could not be included in the proposed course.

Faculty were generally happy with the capabilities of the better students to carry out symbolic manipulations of common problems, particularly if the student had recently been in MA 227 or MA 252. However, all students were very poor at applying their mathematics courses in their engineering courses. The most striking illustration was ME 321: Introduction to Fluid Mechanics, where the instructor reports spending approximately one-third of course re-teaching MA 227 and MA 252 in the context of engineering problem-solving. Curiously, the ME 360: Controls and Automation instructor reported that students who previously had ME 321 exhibited much stronger mathematics skills than those who had not. This anecdotal evidence points to the importance of treating mathematics as a tool for solving engineering problems rather than in isolation.

There was complete agreement, rare in an academic environment, that a problems-based approach would improve the preparation of students for the engineering courses for the following reasons:

- Engineers (and engineering students) tend to look at problems from an applications standpoint. Teaching with this approach is expected to both enhance interest and knowledge retention, as well as to provide a bridge from the “pure” mathematics courses (MA 125 and MA 126) to the engineering curricula.

- A reduced coverage in topics would be more than compensated by a stronger base in the “key” areas and a better understanding of the science/mathematics linkage to engineering problem-solving. It was also noted that the final assessment of the mathematics skills of our students does not occur in MA 252 but during the direct assessment of student work-product from upper-level engineering courses.

- All faculty expressed a willingness to teach any mathematics topics or techniques not covered in the proposed course as needed in their own classes. They felt that the time spent doing this would be equal to or less than what is currently used re- teaching or teaching from an applications standpoint.

- The emphasis on units and reasonableness of the solution are critical to educating engineering students. Most engineering faculty severely downgrade answers without correct units, and unit errors are often the cause of mishaps for practicing engineers. Furthermore, units provide an important clue on the correctness of the solution.

Based on the faculty interviews, discussions with mathematics faculty, a course outline, presented in Figure 2, includes the topics considered most important by engineering faculty members who teach courses for which Calculus III or Differential Equations was listed as a direct prerequisite, or implied as an indirect prerequisite. It should be noted that this outline is a balance among designing a coherent course, meeting the many needs of the engineering programs, and being able to adequately address the topics in a four semester-hour course using active and problem-based learning.

Every faculty member expressed the strong opinion that it was more important for students to deeply understand and apply the topics covered than to be broadly exposed to every mathematical tool which might be utilized in their engineering curriculum. All expressed a willingness to continue to add required tools to the students' mathematical toolbox if needed in their specific curricula. If the proposed list of topics proved to be ambitious for the course, engineering faculty members were willing to cover some of the topics in subsequent required engineering classes. They felt strongly that the educational benefits provided by this course, as outlined in the learning outcomes, discussed below, far outweighed the benefits of exposure to a few additional topics. This focus on deep understanding and application of concepts emphasized the important role pedagogy must play in the success of the new course. Therefore, the instructional approach developed for the course was just as important as the topics covered.

Learning Outcomes

The following learning outcomes reflect the expectations of the engineering faculty as well as the engineering professionals who serve as advisors to the School. Students who complete the newly designed course will be able to:

1. Evaluate engineering problems and choose the tools (from basic sciences and mathematics) required for solving.

2. Utilize appropriate units, constraints, physical constants and associated equations in the solution of engineering problems.

3. Demonstrate an intuition about engineering problems including relationships among variables and mathematical connections.

4. Assess the validity of the mathematical solution using units, physical intuition, and boundary conditions.

5. Categorize engineering problems by common solution structures

6. Utilize a Computer Algebra System (CAS), such as Mathematica, to solve engineering problems.

7. Demonstrate mathematical concepts and computational skills in differential equations and two-and three-dimensional calculus

8. Solve fundamental mathematical problems in each area addressed by the course.

9. Develop the numerical confidence necessary to tackle significant engineering problems and defend their approach and solution.

Pedagogy and Instruction

Developing a course designed to meet the needs of engineering students entailed not only identifying the mathematical topics to include, but also selecting appropriate pedagogy to support the learning outcomes developed for the course, to meet the engineering education goals encouraged by ABET, and to begin to develop the characteristics sought by the professional engineering community in young engineers. There was also the desire to address another issue of concern. Nationwide, low rates of student retention within the discipline of engineering have heightened concerns in the engineering community about the structure and delivery of engineering education[2]. As Hyman Bass[3] eloquently stated in his article Mathematicians as Educators, “Pedagogy is not something to be added after the fact to content. Pedagogy and content are inextricably interwoven in effective teaching. Pedagogy, like language itself, can either liberate or imprison ideas, inspire or suffocate constructive thinking”. This link between what is learned, and how it is learned, was reinforced by the literature.

Course development began with three premises which are supported by mathematics and engineering education literature.

1. People are most strongly motivated to learn things when they can clearly see the usefulness of what they are learning[4] and motivation to learn affects the amount of time students are willing to devote to learning[5]. Therefore, instruction must begin with real-world, professionally relevant situations and problems to provide context for learning the content and skills the course is intended to teach rather than beginning with general principles and eventually getting to applications.

2. Students should play an active role in classrooms which include a range of instructional methods including posing complex engineering challenges[6], discussion of questions and problem solving in class[4], small group work[7], and team learning[8] with the amount of time devoted to traditional lecture greatly reduced.

3. The likelihood that knowledge and skills acquired in one course will transfer to other courses and real world settings is a function of the similarity of the environments[5]. To this end, learning should be organized around authentic problems, projects, and cases. Collaborative teamwork should be emphasized along with individual work, and contextualized reasoning should be emphasized rather than abstract reasoning.

Several well-known instructional models involve learning cycles which embrace these premises. Two of the best known are those of Kolb’s Experiential Learning Model[9], and The Star Legacy Module, developed at Vanderbilt University[10]. Both Kolb’s Model and The Star Legacy Module involve initial challenges or problems to establish a “need to know” and provide context, presentation and discussion of pertinent principles, resources, observations and problem solving approaches, guided hands-on practice, exploration of consequences and applications of the newly learned materials, demonstrated mastery of the knowledge and skills specified in the learning objectives, and use of active learning environments.

The instructional approach developed for this course (Figure 1) is in keeping with these models. Mathematics will be taught in the context of engineering and will be arranged by engineering problem types which share common mathematical solution structures. These engineering problems (challenges) will be introduced by engineering faculty with an exploration of the physical relationships, causes/effects, boundary conditions and units involved. Governing engineering principles will be discussed, and students will explore what they already know about problems of this type. The details of the underlying science and engineering principles of the challenges will not be addressed due to time constraints but will be, of course, addressed in the upper-level appropriate courses. Careful selection of the challenges will allow students to utilize their physical intuition as well. Faculty will guide discussions of what needs to be known in order to know how to solve the problem, and translation of the problem into appropriate equation(s). The mathematical tools required to solve the equations and, thus, the problem will be taught by faculty trained in the teaching of mathematics. Discussion of reasonableness-of-solution will be included. Additional types of engineering problems will be introduced that share common solution structures. Students solve the big engineering problem (challenge) and defend their approach and solution.

This approach focuses on the development of thinking and understanding, the development of engineering and mathematical language, and the development of the confidence required to tackle large engineering projects and persist in finding solutions. Students will be active participants in learning, and small group work will be central to the experience. The initial offering of this course will be Fall semester 2008. The course will be team taught with a faculty member from engineering with a background in mathematics education and a mathematics faculty member. These instructors were involved with the course development. Credit hour production with be divided between the two schools (Natural Science & Mathematics and Engineering). The challenges will be presented by engineering faculty, usually the person who would teach that topic in an upper-level course.

Assessment

This course clearly presents a change in approach, and its success or failure must be assessed. Techniques used to assess the effect of calculus reform on other campuses has included comparison of performance by “traditional” vs. “reform” trained students on selected common exam questions, performance in subsequent courses for which mathematics is a prerequisite, and persistence of students in technical majors[11, 12]. Performance on common examination questions would immediately compare students’ ability to mechanically solve basic math problems and provide some rapid feedback on the cadre of students in the first offering of the new course. Questions could also be added to the “Student Ratings of Instruction” survey for the new course to solicit comments comparing the instructional styles of a traditional MA course and the new course, with a focus on the impact on learning. Performance in subsequent courses would evaluate retention and understanding of the material, with courses taught in Spring 2009 providing early feedback. A long-term comparison of persistence in technical majors would evaluate the effect on student engagement. Direct assessment techniques based on student workproducts will be developed for each learning outcome based on the ABET assessment process, in which the success of each student at attaining the outcomes is examined.

Summary

A mathematics based course that follows Calculus I and Calculus II with an engineering problem-solving emphasis was developed based upon engineering faculty interviews. Each topical area will start with a significant engineering challenge and governing equations before teaching the mathematical techniques. Units and reasonableness-of-solution will be included as vital skills. This course will be taught using active learning and problem-based learning approaches.

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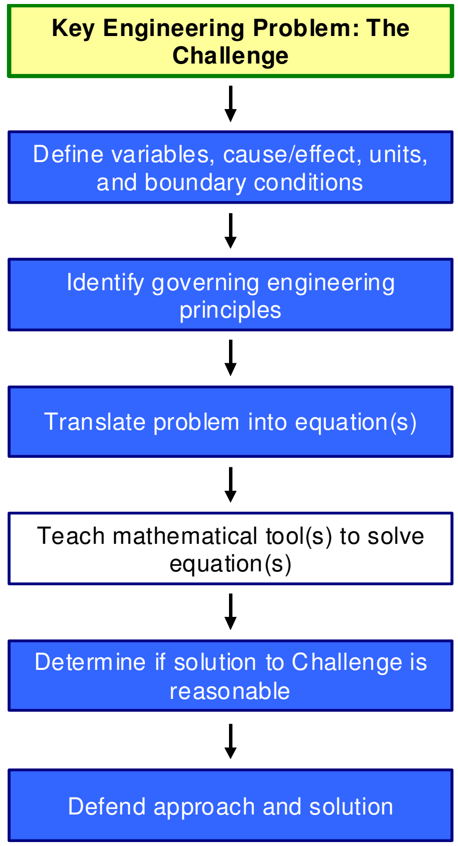

Figure 1: Proposed Methodology for Discussions with Engineering Faculty.

I. First-Order Ordinary Differential Equations (ODEs)
  A. Basic Concepts, Modeling
  B. Initial Value Problems
  C. Direction Fields
  D. Existence and Uniqueness
  E. Separable ODEs
  F. Linear ODEs
  G. Applications

II. Second-Order ODEs
  A. Homogeneous Linear ODEs with constant coefficients
  B. Free Oscillations
  C. Forced Oscillations
  D. Electrical/Mechanical Systems

III. Multivariable Calculus
  A. Functions of Several Variables
  B. Partial Derivatives, Gradients
  C. Divergence and Curl
  D. Line Integrals
  E. Multiple Integrals

IV. Partial Differential Equations
  A. Basic Concepts, Modeling the Wave Equation
  B. Initial and Boundary Conditions
  C. Separating Variables
  D. Fourier Analysis
  E. Eigenvalues and Eigenfunctions

Figure 2: Proposed Course Outline