AC 2010-1363: AN INNOVATIVE UNDERGRADUATE COMPUTATIONAL MATHEMATICS CURRICULUM FOR ENGINEERING STUDENTS SEEKING DUAL MAJOR

Jayathi Raghavan, Embry-Riddle Aeronautical University, Daytona Beach

Hong Liu, Embry-Riddle Aeronautical University, Daytona Beach

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Abstract

In this paper, we discuss the design of a unique undergraduate curriculum in Computational Mathematics for students in the engineering fields who wish to pursue a dual major. At the institution that the authors teach, an undergraduate program in Computational Mathematics has been recently approved. The trend seems to be that most of the students wishing to pursue the degree program are engineering students interested in pursuing a dual major. The challenges faced by the department are 1) to offer these dual majors an integrated curriculum that would take advantage of their engineering background and 2) to offer a curriculum which will enable them to complete the degree within one additional year without compromising the integrity of the program. In this paper, the authors discuss in detail their Computational Mathematics curriculum and the modification of the curriculum for the dual majors.

Introduction

Computational Mathematics is a multidisciplinary field that applies the techniques of mathematics and computer science to solve the problems arising in natural and social sciences as well as various business and engineering fields. In recent years, the accessibility to high performance computers and affordability of low cost clusters of microcomputers have resulted in the surge of interest in development of new degree programs in the area of computational sciences at universities across the country[2-7]. So to be part of the trend, the mathematics department at the our university had proposed[13] a new degree program in Computational Mathematics four years ago and got it finally approved in 2009. Our university is a highly selective private masters granting technical institution that has a few well-established programs in aerospace engineering and aviation sciences. But, most other programs have very limited visibility outside. To be competitive to attract new students and to place them successfully, the degree program introduced has to be innovative and take advantage of the technical strength of our university. So, our degree program targets two groups of students. One group includes the students transferring from other engineering programs or engineering majors interested in pursuing a dual degree with Computational Mathematics as their second major. The other group includes new freshmen from high school. Most of the students currently pursuing the degree program are dual majors. The challenges faced by the department are 1) to offer the same core courses to the two groups of students mentioned above whose academic backgrounds are significantly different, 2) to customize a curriculum that will enable the students in dual major to complete the degree within one additional year without compromising the integrity of the program, and 3) to offer an innovative curriculum so as to attract students to this new degree program under tight budget constraints. In this paper, we discuss how we plan to address some of the issues through the design of our unique undergraduate Computational Mathematics curriculum.

Background

Faculty at our institution has been active in research related to Computational Sciences for many years. Our university has a 128-node cluster of computers funded through NSF to be used for undergraduate education and research. We and other colleagues from our department have attended several workshops conducted by National Computational Science Institute, a major organization involved in developing national initiatives to promote computational science in the K-12 and undergraduate curriculum [1]. Our department had also sponsored some of these summer workshops. These workshops introduce resources and modeling and simulation tools like Stella [12], Agentsheets, MATLAB, and Madonna to K-12 teachers and college faculty to help students acquire computational thinking, abstraction and modeling skills that are essential to solve real-world application problems. We have authored several computational modules which have been presented, published and were used in our undergraduate honors classes. We have also been involved in developing a framework to create computational mathematics modules that help improve students' abstraction capabilities [8-11]. These workshops and activities served as a springboard for our department to draft and submit the proposal for the degree program in Computational Mathematics. Prior to the proposal of the degree program, several similar programs at other universities were researched like Princeton, Rice, Stanford, George Mason and University of Chicago [4,6,7]. But none of those universities had the unique characteristic of our university where majority of the students are either engineering or aviation majors. So, a computational mathematics degree was proposed taking the essence of these similar degree programs and adapting them to the strengths of our university.

Computational Mathematics Degree Program

As mentioned earlier our university is a selective private masters granting technical university. The purpose of our university is "..to provide a comprehensive education to prepare graduates for productive careers and responsible citizenship with special emphasis on the needs of aviation, aerospace, engineering, or related fields…". To achieve this, the following education goals were developed for the degree program with focus areas in computational engineering and sciences.

    a. The degree program will ensure that students develop abilities in critical thinking, problem solving, written and oral communication, quantitative analysis, leadership and teamwork, ethics and values awareness, and information technology

    b. The student will acquire a strong background in applied mathematics with an emphasis on computational methods

    c. The student will acquire a foundation in physics, computing tools and engineering science necessary to understand how each relates to realistic applications in at least one science application area

    d. The student will be exposed to computational applications in the sciences and engineering. The student will learn how to synthesize the mathematics, computing, physics, and engineering to effectively analyze a complex problem arising from a variety of application fields.

    e. The student will learn how to work collaboratively and productively on complex projects that arise in current research. These projects will provide a capstone experience for students in this degree.

f. The student, upon completion of this program, will be able to find employment in a large number of industries including aviation and aerospace industries, or the student, upon completion of this program, will be able to pursue graduate work in either an applied mathematics program or a computational science program.

g. The department will engage in a process of assessment and improvement of this degree program to ensure that the goals and objectives are being met.

The following section briefly describes the design of the curriculum to achieve these degree program goals.

Computational Mathematics Curriculum Design

The Computational Mathematics (CM) curriculum requires that our students complete 120 credit hours to earn a bachelor degree. The following table provides summary of credit hours the students are required to complete in the different subject areas.

Subject Area	Credit Hours	
	Required for Computational Mathematics	Common to Engineering students
General Education 　　Mathematics (6) 　　Physics (6) 　　Computer Science (3) 　　Communication Theory & Skills (9) 　　Humanities and Social Sciences (12)	36	36
Applied Mathematics	43	13
Physical Sciences	9	9
Computer Science	10	
Engineering Sciences	9	9
Open electives	10	10
Capstone	3	
Total Degree Credits	120	77

The required Computer Science courses provide them a background in MATALB, C, UNIX and Java programming. The required Engineering and Physics courses provide the students with a background in Statics, Dynamics and Fluid Mechanics. All the courses include applications to science and engineering fields. Currently only engineering track is offered due to the engineering focus of the university. There is a plan to add an additional track in data sciences in the near

future. To satisfy ABET requirement, all engineering students are required to take at least 19 hours of Mathematics and most of the students at our institution take an additional 3 credit hours of Mathematics course toward their technical elective which also earn them a minor in Applied Mathematics. All the engineering and physical sciences courses required for Computational Mathematics degree are also required for engineering students. Any engineering student will require an additional 43 credit hours to earn a dual degree in Computational Mathematics. So if a student wishes to dual major in engineering and computational mathematics, a careful planning will only require additional 37 credit hours of computational mathematics courses, since 6 of the 43 credits will count towards technical elective for their engineering degree. So students can earn their dual degree within just one additional year including a summer.

Core Courses and their Objectives

The core courses in the curriculum include: a one credit introductory Seminar Course to Computational Mathematics which can be repeated over three semesters, Numerical Methods in ODEs and PDEs, High Performance Computing and Scientific Visualization. The Capstone Project course would require the students to demonstrate their ability to solve real-world problems in science and engineering using the computational mathematics tools. The seminar and capstone courses are coordinated by an individual instructor but co-taught by multiple instructors so that the students can choose their mentors and projects to fit their academic background and career interests.

The major challenge to the degree program in computational mathematics at our university is that the very small student body comes from a varied academic background, with the dual majors having a stronger engineering background than others. Maintaining very high retention is crucial to the success of the new degree program. The Computational Mathematics Seminar and Capstone courses are uniquely designed to offer students individualized education to best serve their career interests and previous academic preparation.

Freshman Seminar Course

As the first core course of this unique curriculum, the purpose of the seminar course is to increase student retention and motivation by exploring a broad variety of interdisciplinary computational mathematics applications and transforming the students' learning through mathematical modeling and simulation. The prominence of computation in all topics of the course is a key distinction between this course and other applied mathematics courses. This course starts at freshman level, runs once a week and continues for three successive semesters. To help the degree program maintain high retention rate, this course offers opportunities for all students and several faculty members in our department to get to know one another and to engage in a working relationship at the earliest stage. The major part of the course is taught by the course coordinator, with the remaining co-taught by other faculty members within the program. The instructors use this opportunity to show their expertise and research interest which will enable the students to choose their area of interest and faculty mentors to complete their required team projects. The positive working relationship also helps the instructors and students to identify topics of mutual interest for the capstone course and projects.

The primary goals of the course are:

1. to nurture students' curiosity to seek understanding and solutions to computational mathematics problems

2. to prepare students with the software tools (MSEXELL, STELLA, MATLAB, Agentsheets) and problem solving skills needed for the upper level core courses, especially the capstone course

3. to introduce students to interesting team projects in computational mathematics in the earliest stage.

The author observes that many freshman college students demonstrate little ability to extend mathematical concepts beyond an algorithmic level [9]. The multiple choice problems in standard mathematics tests in high school tend to motivate students either to give a quick answer to a problem or to omit the problem altogether. This habit significantly limits students' ability to tackle complex real-world applications in computational mathematics. This course will guide the students to follow a rigorous system engineering process and methodology to seek intuitive understanding to the problems under consideration. They will learn how to look for qualitative answers before complex quantitative computation.

Capstone Course

The capstone course is the last core course of the degree program. Similar to the seminar course, it is co-taught by a course coordinator and several other instructors who serve as project mentors. Currently, all of our dual major students have engineering background. A prerequisite to the capstone course is that the students have to register in least one of the elective courses in another major field such as fluid dynamics, space physics etc. This prerequisite poses no additional course requirement for the students in dual majors, since they would have taken this course for their second major. But, it demands that our faculty mentors have the expertise in all those different fields. This is not of a major concern, since in addition to the terminal degree in mathematics, several faculty members at our department have either a Bachelors or a Masters degree in other disciplines and have been cooperating with faculty members from other departments on several projects over the years. Based on the expertise of the faculty members involved and the academic background of our students, we currently plan to offer capstone courses with focus area in computational fluid dynamics, space physics and software engineering applications.

The final project is a summative evaluation of the course. A student is required to use sound scientific approach to investigate an application problem in which mathematical modeling and computation play a pivotal role to the solution. The primary goals of the course are that the students demonstrate the ability to

1. Apply engineering principles, systematic methodology, mathematical analysis as well as computational software tools to solve the problem under concern.

2. Use modeling, simulation and scientific visualization to intuitively present, validate and verify the solutions.

3. Write a professional technical report for the investigation and discovery and present an objective assessment of the reliability and limitation of the solutions.

Current Status and Future Work

Our University is a selective private university whose main focus is in aerospace engineering, aviation business and sciences. Because most students with a good aptitude for mathematics are engineering majors, our first recruiting strategy is to target those engineering majors who are interested in pursuing graduate studies in computational engineering and/or in applying mathematics and computing techniques to real-world problems in engineering industry. Currently, we have about a dozen engineering students enrolled in the Computational Mathematics program pursuing a double major. In fall 2010, our department will be offering two core computational mathematics courses mainly for students in Computational Mathematics program but which can also be taken by students in other programs requiring a technical elective. The two courses are the Freshman Seminar Course and the Scientific Visualization course. More details about the degree program can be found at the website http://eraucomputationalmath.com/index.html. Since the degree program is at its infancy stage, we cannot talk much about the formal assessment of the performance of the students within the program. Informally, we have observed some positive feedback from students enrolled in the program as well as the IAB (industry advising board). The members of IAB offered several invitations of internship positions, more than the number of applicants that we can send from our degree program.

Our next step will be to introduce another focus area in computational data sciences mainly for non-dual majors. For this track, besides replacing the courses in physics sciences and engineering fields with business courses and additional computer science courses, some advanced mathematics courses such as PDE and numerical PDE will be replaced with some courses in regression analysis, experimental design and data mining. Of course, the capstone course will require the students to work on problems involving data science applications, with all other core courses unchanged. We anticipate that most future freshman students in the program will opt for the focus area in computational data sciences.

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