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AN INTERDISCIPLINARY, MULTISEMESTER PROJECT RELATING DIFFERENTIAL EQUATIONS AND ENGINEERING

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Abstract

Students often do not see the relevance of their mathematics courses to courses in their majors or to their careers. Consequently, their motivation to learn the material in mathematics courses is low, and their retention of this material is poor.

This paper describes an interdisciplinary, multisemester project designed to lead students to appreciate the relevance and importance of basic STEM (Science, Technology, Engineering and Mathematics) material. Starting in the sophomore level differential equations course and continuing in junior and senior level engineering courses, students analyze dynamic systems from various points of view, including mathematical modeling. This paper describes the project and the modules being developed to implement it.

Introduction

Mathematicians teaching service courses for engineering students face a challenging problem. They know it is important for their students to learn the material in these courses. (See [3], for example.) However, they speak “mathematics” and not “engineering,” making it difficult for them to communicate the relevance of the material to their students.

The students face a similar problem. They know there is a reason they are required to take mathematics courses, but the reason usually does not become apparent until long after the courses have ended. Consequently, students’ motivation to learn the mathematics is not as great as it could be. Furthermore, by the time they need the mathematics in their upper level engineering courses, they have forgotten much of it because they have not used it in such a long time.

This paper describes an attempt to alleviate the joint problems of motivation and retention of material by means of a project extending over several courses and spanning several semesters.

The paper is written from the perspective of a mathematician trying to learn to speak "engineering." An overview of the project is given in the next section, and some details of the implementation are given in the following section.

Project Description

For the sake of definiteness, this paper will focus on the mechanical engineering curriculum at the University of Massachusetts Lowell (UML), but the concepts described here can also be applied to other engineering disciplines and other institutions. The project under development spans five courses:

1. Engineering Differential Equations, offered by the Department of Mathematical Sciences, normally taken in the second semester of the sophomore year;
2. Applied Analysis, offered by the Mechanical Engineering Department, normally taken in the first semester of the junior year;
3. Mechanical Engineering Lab I, offered by the Mechanical Engineering Department, normally taken in the second semester of the junior year;
4. Mechanical Engineering Lab II, offered by the Mechanical Engineering Department, normally taken in the first semester of the senior year; and
5. Dynamic Systems, offered by the Mechanical Engineering Department, normally taken in the first semester of the senior year.

By virtue of the timing of these courses, the project material will be revisited in each of four successive semesters. Each semester, students will be reminded of what they already know about the project material and will also apply newly learned techniques from the current course. This paper will discuss those aspects of the project related specifically to the Engineering Differential Equations course. For a more comprehensive view of the project, see [1] and [2].

Differential equations courses have traditionally focused on techniques for generating solution formulas. Even in applications, the differential equation was the object of interest, and the goal was to obtain a solution formula. From the engineering point of view, however, the system being modeled is the object of interest, and the goal is to understand how the system responds to different classes of inputs, including step functions, impulses, and sinusoids. With the advent of the UML project, our Engineering Differential Equations course has been modified to reflect more of the engineering point of view.

The UML project currently involves two systems: a simple RC series circuit (modeled by a first-order linear differential equation), and a forced mass-spring-dashpot system (modeled by a second-order linear differential equation). In the differential equations course, students learn how to model each of these systems by a differential equation, and they learn analytical techniques for finding solutions of the model equations. They now also use the solution formulas to investigate the response of the modeled system to different types of input. In subsequent courses, students work with actual measured data, comparing the measured system response to the theoretical response and dealing with issues such as noisy and biased data.

For the RC circuit, students investigate how the system responds to a constant (or step function) input and to a sinusoidal input. For the constant input, they see that the response approaches a constant value, and they investigate how the speed of the response depends on the values of the resistance and capacitance. For the sinusoidal input, students see that the response settles into a sinusoidal steady state, and they investigate how the amplitude and phase of the response depend on the input frequency. A Bode plot reveals how response amplitude decreases as input frequency increases, so students see how the circuit can function as a low-pass filter.

For the mass-spring-dashpot system, students investigate how the system responds to impulse forcing and to sinusoidal forcing. They see that an impulse forcing is equivalent to specifying an initial velocity. For the sinusoidal forcing, students see that the response settles into a sinusoidal steady state, and they investigate how the amplitude and phase of the response depend on the input frequency. From a plot of response amplitude vs. input frequency, they can investigate the possibility of resonance.

Project Modules

One of the goals of the UML project is to develop self-contained modules to facilitate student learning and to facilitate adoption and modification of project materials by other users. Each module consists of a brief description of the theoretical aspects of the system under consideration and computer-based tools to allow students to investigate the behavior of the system. The computer-based tools were developed using the MATLAB, Simulink, and Labview software packages. (Instructions are included with each module.) A graphical user interface (GUI) allows for the easy adjustment of system parameters so the student can explore the effects of changing parameter values on system response.

The MATLAB GUI and Labview GUI for the RC circuit are shown in Figure 1. The GUI allows the student to specify the time constant and the excitation/source sinusoidal frequency; the values can be easily adjusted via keyboard entry or scroll bar values. The Bode plots (magnitude/phase) are displayed (with the cutoff frequency) along with the source and filtered time sinusoidal signal.

Students can investigate the frequency response of a mass-spring-dashpot system using the MATLAB or Labview GUI's shown in Figure 2. The students specify the mass, damping and stiffness values via keyboard entry or scroll bar values. The frequency, damping, critical damping, etc. of the system are reported along with plots of the time response, frequency response and the root locus plot. As values are changed the plots update and the plot of the poles in the s-plane are easily observed.

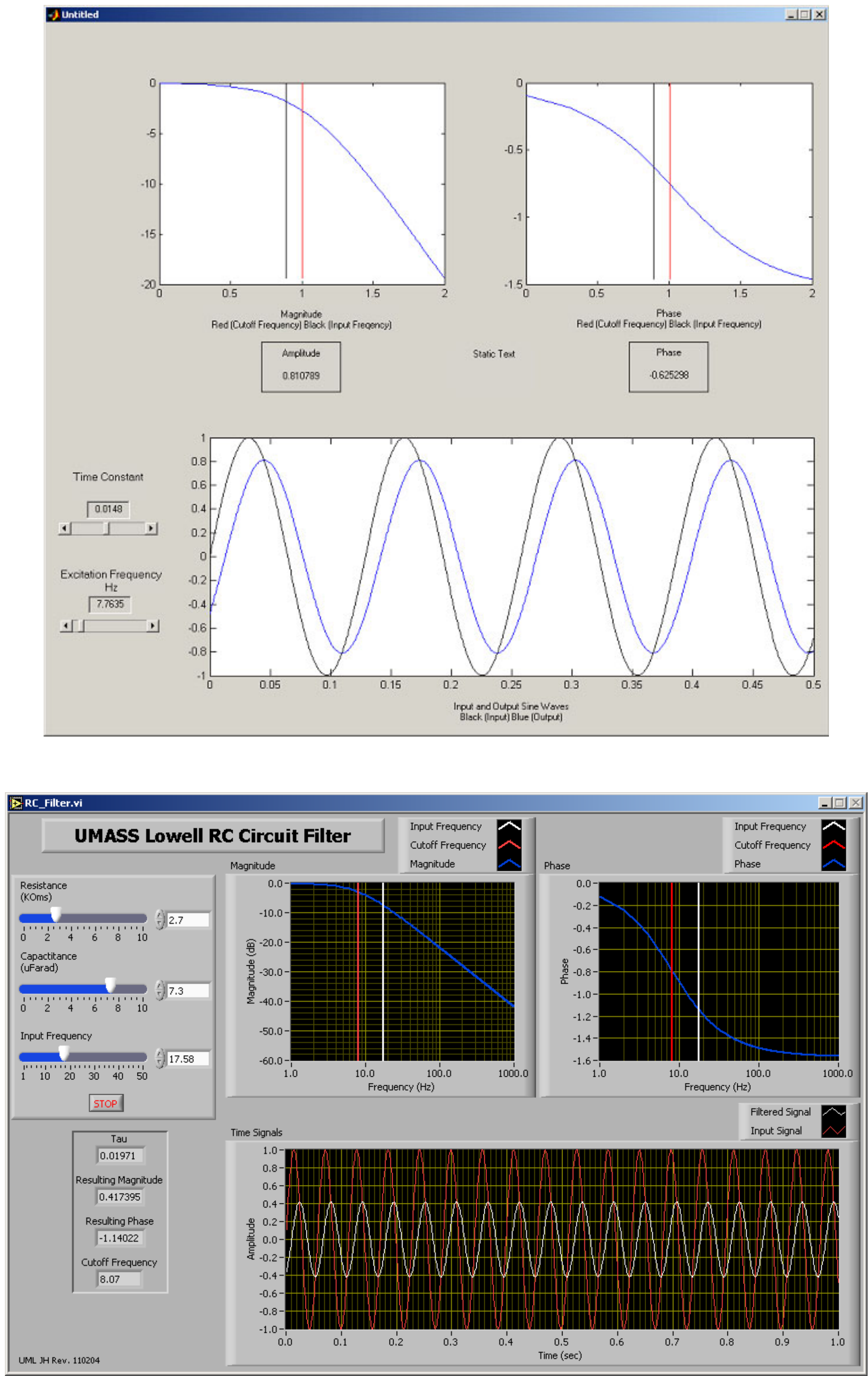

Figure 1 - First Order Low Pass Filter GUI

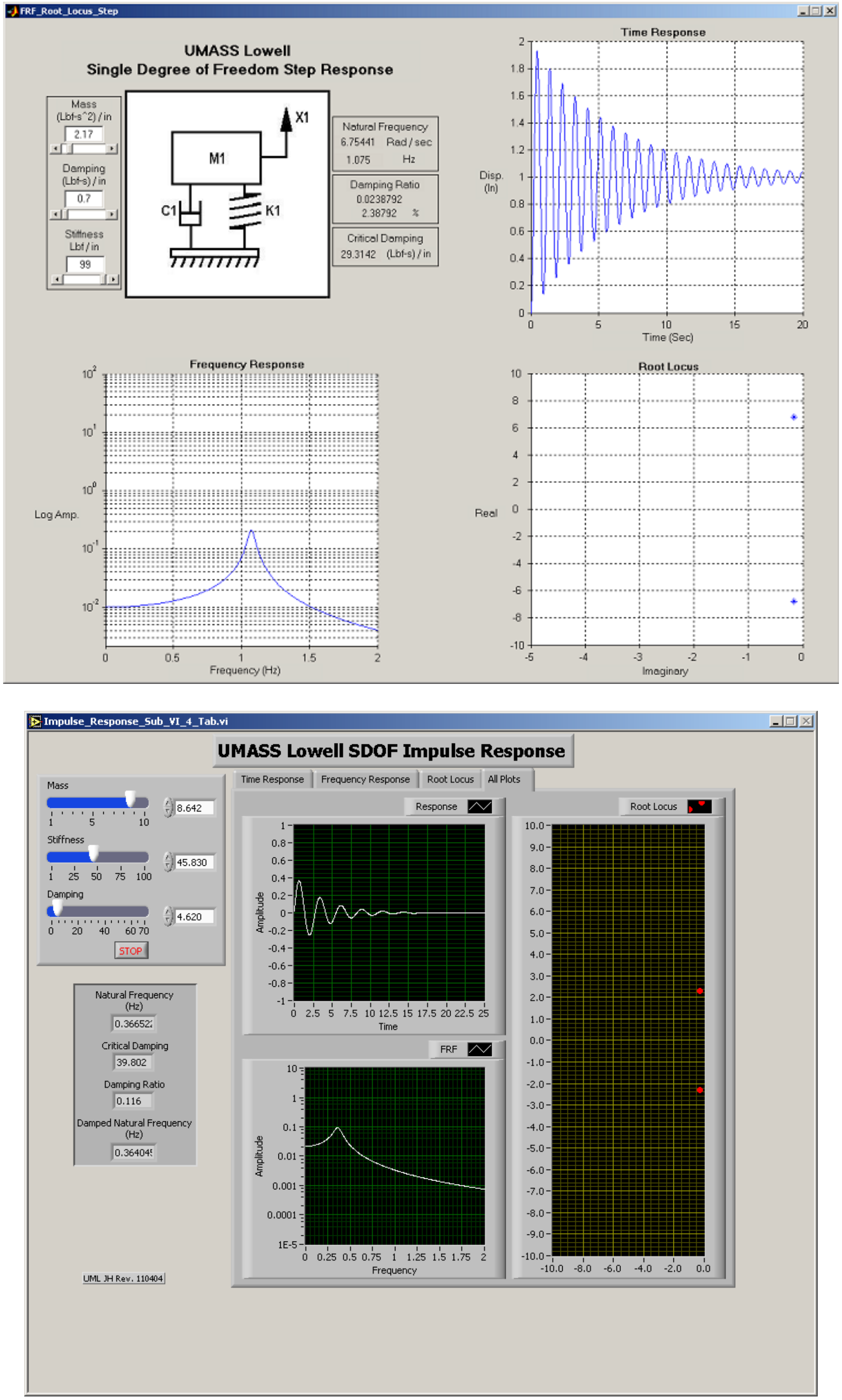

Figure 2 - Second Order System Step Response GUI

Preliminary Assessment

The UML project is only in its second year, so complete data on the program's effectiveness are not yet available. However, there are preliminary indications that the project is having a positive effect on student attitudes. Students in the Engineering Differential Equations course were surveyed at the beginning and at the end of the Fall 2004 semester. The students were asked to respond to 17 statements, indicating whether they strongly agreed, somewhat agreed, had no opinion, somewhat disagreed, or strongly disagreed. The first four statements were

1. I understand the need for ordinary differential equations in course work for my major.
2. I understand the need for ordinary differential equations in solving practical problems in engineering and science.
3. The material from this course will be useful to me in courses in my major.
4. The material from this course will be useful to me in my career.

Table 1 shows the percent of respondents who either strongly agreed or somewhat agreed with these four statements; Table 2 shows the percent of respondents who strongly agreed. The data appear to indicate an increase in student awareness of the need for differential equations during the course of the semester.

	Question 1	Question 2	Question 3	Question 4
Start of semester	75%	79%	79%	54%
End of semester	100%	100%	100%	78%

Table 1. Percent of students who either strongly agreed or somewhat agreed with four statements regarding the utility of differential equations.

	Question 1	Question 2	Question 3	Question 4
Start of semester	29%	38%	25%	21%
End of semester	56%	56%	67%	28%

Table 2. Percent of students who strongly agreed with four statements regarding the utility of differential equations.

Conclusion

A new interdisciplinary, multisemester dynamic systems project was described in this paper. The main feature of the project is that material from differential equations and upper level engineering courses is integrated in a fashion that helps the students understand the need for basic STEM (Science, Technology, Engineering and Mathematics) material. Two specific systems, a simple RC circuit and a mass-spring-dashpot system, are studied from different points of view in each of four successive semesters. Graphical user interfaces have been developed to allow students to explore the behavior of these systems.

Acknowledgments

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