# TEACHING DIFFERENTIAL EQUATIONS FOR ENGINEERING STUDENTS: AN INTERACTIVE APPROACH

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## Abstract

Computer based learning has become an essential part of education systems. It provides animation and interactive processes that are not possible with textbooks. Not only SIMULINK has a great impact on industry, it also dramatically affects traditional academic research and teaching. A SIMULINK-based laboratory makes researchers more productive and improves the way students learn. Rather than focusing on sometimes-tedious theory and solution methods, educators and students can focus on results and concepts. In this paper, we present an Interactive Internet application of SIMULINK in computer based teaching and learning, with emphasis on the domain of differential equations applied to engineering applications. The students' experiments component is supported with both virtual and real-time remote laboratory. The discussions include the design, implementation plan, and instructional method.

**Keywords:** Interactive Internet based learning, Computer assisted instruction, SIMULINK, Virtual Laboratory, Visualization, Spring-Mass-Damper Motion, Differential Equations.

## Introduction

Along with the advancement of computers and the advent of the Internet, the field of education has taken on new dimensions. This new technology includes Internet based research and learning and serves well as complimentary tools in education. In this paper, we develop an interactive web based activity that is aimed at teaching differential equations concepts through applications in physical sciences and problem solving to college juniors and seniors. It involves the

development of an interactive web-based learning environment for basic differential equations concepts. The major objectives are: students' understanding enhancement, problem-solving skills improvement, and instructional theories and methods enrichment.

Differential Equations is an area where engineering students find difficulties in understanding basic concepts, solving problems and applying them to different fields. This is due to several reasons that include the tedious nature of theory such as the use of higher order differential equations, and the analysis of systems of differential equations [5, 7]. There have been several attempts to employ available technology and World Wide Web to resolve various problems encountered by students [3, 4].

The basic design includes guide, simulation/visualization, web-interaction, and help sessions. The guide provides expert opinions to students. It guides them on topics relevant to solving the problems. The simulation and visualization sector is very important in areas such as differential equations were many tools and methods are not easy to follow and comprehend. In our teaching method, students get enough chances to solve the problems. The implementation will be achieved using HTML, library browser that allows the selection of blocks from libraries of standard blocks (SIMULINK). For modeling, SIMULINK provides a graphical user interface (GUI) for building models as block diagrams, using click-and drag mouse operations. Some visualization simulations will use JAVA applets that are programmed to pop up in a new window. SIMULINK makes it easy to provide both virtual and remote laboratory experiments to students. Clients with passwords could access this tutoring/learning system, including the virtual and remote laboratories, via a web browser in any computer (without SIMULINK application) connected to the Internet. There are several research groups working on computer based learning systems that employ SIMULINK [3, 4, 8]. This paper presents the component of the tutoring system that involves the Internet application of SIMULINK for Virtual Lab and real-time remote laboratory experiments.

## Fundamental Issues

In designing the framework for an interactive computer/Internet based learning instructional systems and intelligent systems, there are fundamental issues that need to be addressed. These issues surround the communication of knowledge to the student. In designing computer assisted instruction and Internet based tutoring systems one need to consider the domain, student, communication strategies, and the interface. The design of the path/navigation `through the proposed interactive internet based computer-assisted instructional system is shown in Fig. 1. This is a modification of the structure presented by Shute and Psotka [9, 6].

### The Domain Knowledge

It is necessary to have excellent expertise in the domain of instruction in order to be a good source of the knowledge to be presented. The organization of the knowledge for easy communication to the student, and for best representation and understanding of concepts and their applications are important. In the domain of differential equations, the knowledge to be

conveyed to the student must be organized to avoid misconception of abstract and invisible concepts such as resonance, steady state, damping, etc.
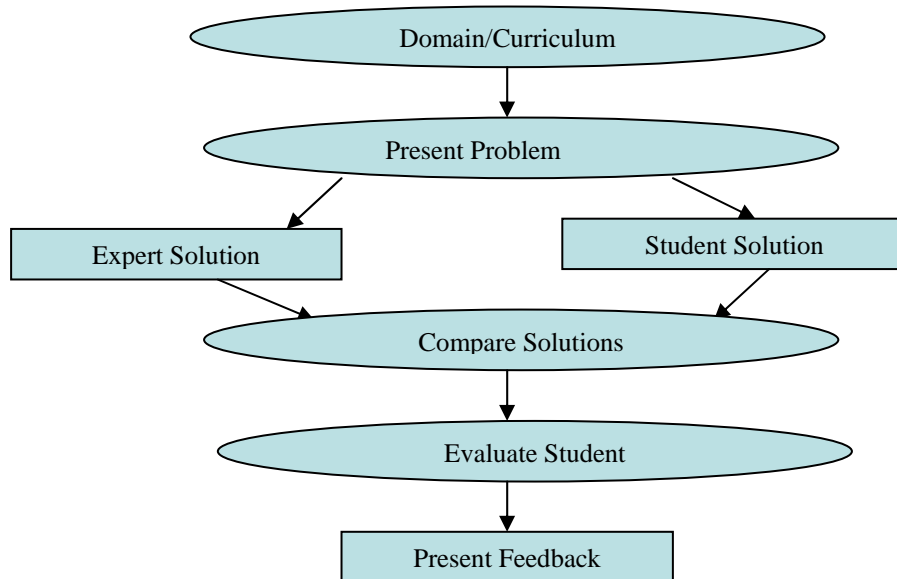
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Fig.1: The design of the path/navigation through an interactive internet based computer assisted instructional system

## Knowledge of the Students

It is important to understand the behavior of the student, previous knowledge and experience of the student that might affect his/her learning characteristics, and the adaptability to the instructional system. Building knowledge about the student need appropriate diagnostic techniques. In differential equations for example, preliminary questions and problems could be used in assessing the student's previous knowledge and experience. One could identify any misconceptions by analyzing the student's response to questions and problems. This will be useful in determining the next set and level of problems, the type of visualization aids and simulation of concepts, and the method of materials presentation.

## Pedagogical Knowledge

Communication strategies are important part of the set up. In differential equations, one must be sure that the way materials are presented will not lead to misconceptions. This is important in using animation for visualization purposes. One must exercise good judgment in deciding when, where, and how to present animation JAVA applets, virtual laboratory experiments, and real-time remote lab experiments. Good communication skills however need good understanding of the materials to be presented, the audience or recipient, and the available interface or means of communication.

**Interfaces with the Students**

The interface component also need knowledge of the above three components. For example in direction fields, the knowledge about the student will determine if graphical presentation will be adequate or there will be need for animated JAVA applet images. Some other questions may include how problems, response and feedbacks are handled; how many interactive windows are needed; and should a pop-up new window used? These are few of the many issues that need to be addressed.

# Design and Implementation

SIMULINK is a software package that enables the student to model, simulate, and analyze systems. It is built on top of MATLAB, which is widely available. It supports linear and nonlinear systems, modeled in continuous time, sampled time, or hybrid of the two. Such systems are often referred to as dynamics systems. SIMULINK provides a graphical user interface that uses various types of elements called blocks to create a simulation of a dynamic system. SIMULINK can be used to explore the behavior of a wide range of real-world dynamic systems, including mechanical, thermal and electrical systems.

Simulating a dynamic system is a two–step process with SIMULINK. First, the user creates a graphical model of the system to be simulated, using the Simulink model editor. The model depicts the time-dependent mathematical relationship among the system's inputs, states and outputs. Then, SIMULINK can be used to simulate the behavior of the system over a specified time span.

SIMULINK can be used to solve ODEs. Most of the vibrations encountered in engineering applications can be represented by a simple harmonic motion. Many others, although of a different type, can be approximated by a simple harmonic motion, provided that their amplitude remains small. Consider, for example, a mechanical spring-mass-damper motion step response.

Students will have access to MATLAB/SIMULINK through a lab set up or remotely via a university server. Each team of students is expected to develop a SIMULINK model for a given differential equation (dynamical system) then use it to find the solution and study its behavior in response to changing some parameters of the given differential equation (dynamical system).

**SIMULINK Model**

The objective of the following exercise is to demonstrate that SIMULINK can be used interactively to solve a second-order differential equation. We show in this exercise how to develop a SIMULINK model to simulate the motion y(t) of a mass, m, in response to a unit step, f(t) = u(t) N, and to produce a graph of y(t) for $0 \leq t \leq 100$ s  as shown in Fig. 2.

The system differential equation is based on Newton's second law of motion, $F_{net} = m\,a$ :

$$m\frac{d^2y}{dt^2} = f(t) - k\,y - c\frac{dy}{dt} \qquad (1)$$

The input is given by f(t) , and the output is y(t) . Let m = 10 kg , k = 1 N/m , and c = 0.5 N-s/m .

Furthermore, SIMULINK can be used to compare differential systems using different methods. For instance, the above mentioned system could be solved using the Laplace transform of the describing differential equation. Assume zero initial conditions. Determine the transfer function Y(s) / F(s). For a unit step input, f(t) = u(t) N, determine the motion response, y(t).  The student can develop a SIMULINK model which uses the Transfer Function block (from the Linear library), driven by a Step Function block, and output to a Scope block or a xy-Graph block, or produce a plot of  y(t)  for 0 ≤ t ≤ 100 s as shown in Fig. 3.

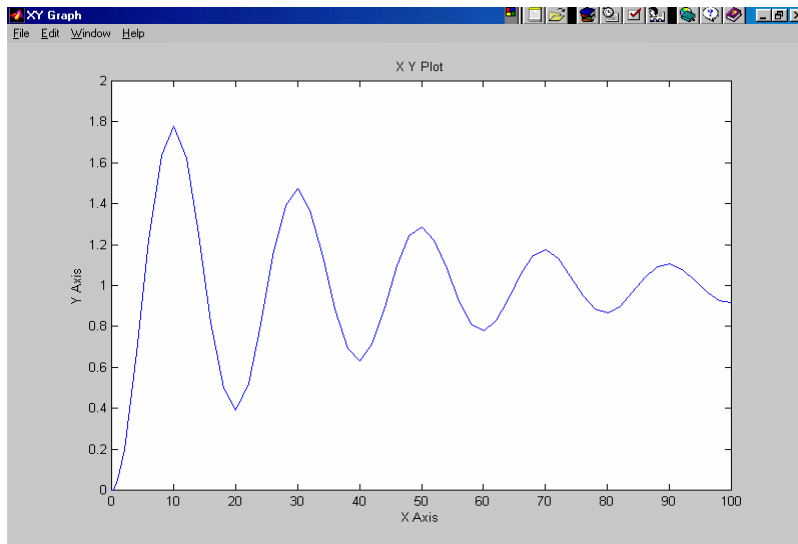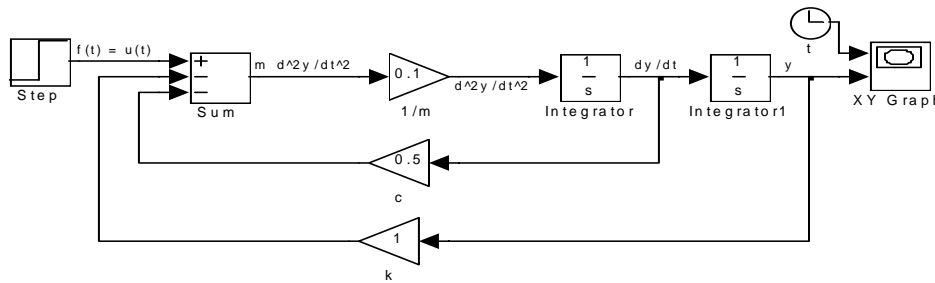

Fig. 2. Block diagram and solution of a Spring-Mass-Damper.

The Laplace transform of DEFQ:

$$L\left[m\frac{d^2y}{dt^2} = f(t) - k\,y - c\frac{dy}{dt}\right], \quad \Rightarrow \quad L\left[m\frac{d^2y}{dt^2}\right] = L[f(t)] - L[k\,y] - L\left[c\frac{dy}{dt}\right]$$

$$m\,s^2 Y(s) = F(s) - k\,Y(s) - c\,s\,Y(s), \quad \Rightarrow \quad (m\,s^2 + c\,s + k)Y(s) = F(s)$$

$$transfer\ function, \quad \frac{Y(s)}{F(s)} = \frac{1}{m\,s^2 + c\,s + k}$$

$$= \frac{1}{10\,s^2 + 0.5\,s + 1} \quad or \quad \frac{0.1}{s^2 + 0.05\,s + 0.1}$$
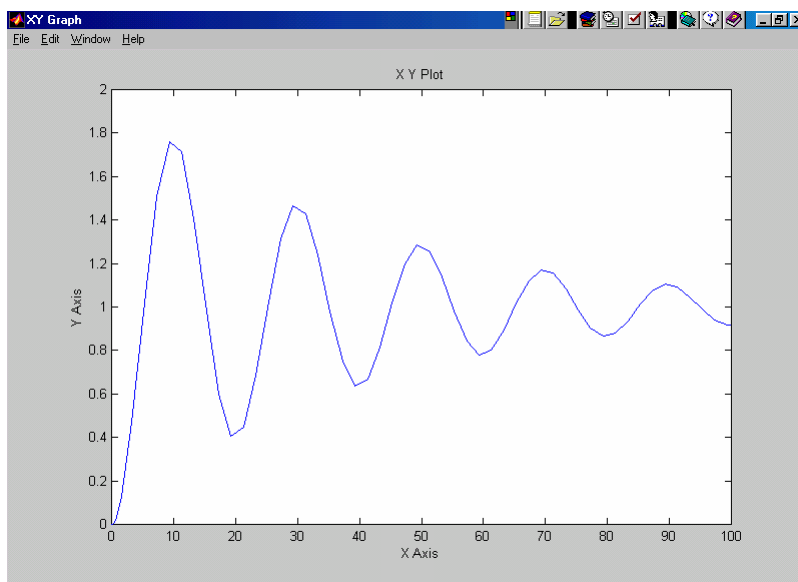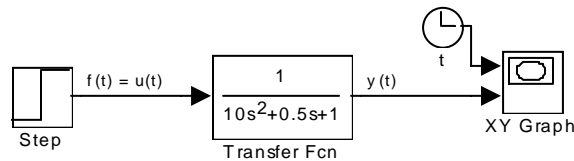




Figure (3): Simulating the motion of a Spring-Mass-Damper

## Conclusion

The framework for an Internet based tutoring/learning system that uses SIMULINK to present an experiment in the domain of differential equations have been designed .The experiment's component is a hybrid of a virtual lab and a real time remote laboratory. Authorized user from a

web browser via the Internet could access both labs. The basic design of the remote lab of the motion of a spring-mass-damper motion has been presented to demonstrate how SIMULINK and its Internet Toolkit can be used to implement the virtual laboratory. Also, differential equations analysis tools are included in the virtual lab component. This tutoring system will serve as an excellent compliment to classroom teaching and learning of Differential Equations. Our ultimate goal is to design more labs in the differential equations area and to extend this idea to other mathematics courses.

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