Using telematics to overcome educational constraints: teaching differential equations using the world-wide-web and multimedia technology

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Abstract

A university course to introduce sophomore (second-year) physics university students to differential equations with the help of the world-wide-web and interactive multimedia technology is currently being designed and implemented at the Physics Department of the University of Crete. On-line differential equation solvers, interactive multimedia demonstrations, lecture notes and a set of worked examples on contemporary physics and real-life applications (chosen to reveal similarities between subfields of physics or between physics and other sciences,) and student term-projects on modern science developments, aim at improving the conceptual understanding and the problem-solving ability of the physics majors.

Keywords

Tools for distance education, Web applications, Interactive multimedia, Differential equations, Physics

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1. INTRODUCTION

The physics curriculum, as presently taught, was developed over thirty years ago (Redish and Wilson, 1993). Although physics has changed a lot during these years, the curriculum has not changed very much. Thus, the introductory college student rarely gets any hint of modern developments or of the excitement of doing physics and learning new things about the world that no one has known before. Another shortcoming is that, although standard instruction introduces students to the basic content of physics, it provides almost no activities that illustrate how research is done. To professional physicists, much of the pleasure of doing physics is associated with satisfying curiosity and learning surprising relationships and analogies of structure. Very little of this joy of the profession is present in the traditional introductory physics courses. Furthermore, research on student conceptual understanding has shown that many physics students entering college today have been trained to associate learning physics with memorization and application of memorized laws in narrowly defined situations. The traditional introductory courses do little to counter them on these views. An additional obstacle is the limited mathematical ability of the introductory student. Creative and open-ended problems require a level of mathematical sophistication (using analytical tools) usually not obtained by students until their third year of college.

The recent immense growth in the power and availability of computer tools and technology can help overcome the above mentioned constraints that have kept the physics curriculum from introducing more creative science at an early educational stage. The power of present-day computational environments can enable students to solve more interesting problems in the introductory course with relatively little training (Mestre et al., 1993.) In this paper, we will describe such a computational environment which we have designed and implemented in the context of the "Introduction to Differential Equations" course taught to sophomore physics majors at the Physics Department of the University of Crete. It comprises an environment where the students can access (in the course's web-site) course-notes and homework assignments, on-line differential equation solvers, animated interactive demonstrations, solved problems on contemporary physics and real-life applications, and the term-project reports (on modern science problems) of students. Shortly, a stand-alone interactive multimedia CD-ROM will be handed-in. Our objective is to instill the excitement, curiosity, and creativity of doing physics in the physics majors and develop their conceptual understanding and problem-solving skills.

2. THE PERCEIVED EDUCATIONAL NEEDS OF PHYSICS STUDENTS

Research on student conceptual understanding over the past decade has shown that many students are not developing a satisfactory conceptual understanding of basic physics (Goldberg and Bendall, 1995). Many of these studies have documented the difficulties students have making connections between various representations (graphs, diagrams, equations), basic concepts and principles, and real world phenomena (McDermott et al., 1987.) What has become apparent is that many decisions students make about the behaviour of physical systems seem to be driven more by prior knowledge and beliefs than by interpretations and applications of formal physics principles (Johansson et al., 1985.) Other studies have shown that students' knowledge often seems to consist of separate facts, formulas, and equations organized poorly for retention and use (Van Heuvelen, 1991.) A study by Hammer (1994) suggests that students may hold the belief that physics is just a collection of symbols, formulas, and the rules of manipulating them

Teaching differential equations should focus on improving the knowledge structure and the problem-solving ability of physics majors; this will be discussed in the following section. This objective can be achieved by immersing the student in an educational environment where he or she will integrate principles, concepts, and procedures. The main intent is to highlight the role of concepts and procedures in problem solving and in doing so to counter novices' tendency to rely on formulaic problem-solving approaches.

3. TEACHING DIFFERENTIAL EQUATIONS: THE EDUCATIONAL OBJECTIVE

In physics alone, most physical phenomena, whether in the domain of fluid dynamics, electricity, magnetism, mechanics, optics, or heat flow, can be described in general by differential equations; in fact, most of mathematical physics is differential equations.

Differential equations provide an extremely fertile ground to 'tie' similar phenomena together (wherever they may appear - either between subfields of physics such as in mechanics, acoustics, optics, electricity, heat, and theoretical physics, or between physics and allied scientific disciplines - see also, Shive and Weber, 1982.) Focusing on such similarities, students develop a more comprehensive view of nature and achieve confidence in dealing with new ideas, whether encountered in textbook problems or in real life situations. In addition to this aspect, the philosophy behind putting "Introduction to Differential Equations" in the Web is to make mathematics more useful, enjoyable, and readily available for all students. The basic technique is to engage students in situations so that they are motivated to "explore" phenomena and problems in physics and allied disciplines, and make use of the solvers and/or the computer when appropriate.

Our approach to the use of the computational tools is based on the following three principles (Redish and Wilson, 1993):

- It is not enough to use the computer to illustrate examples from the current curriculum. We must rethink the curriculum from the ground up, now assuming the availability of the computer. What can we teach now, with the help of current computer technology, that we couldn't teach before?

• The computer should not replace anything in the current educational environment: not the textbook, not the teacher, not the laboratory.
• The student should run the computer, not the other way round.

4. DESIGNING AND IMPLEMENTING A WEB-BASED COURSE

With the above mentioned goals in mind, we have designed and implemented a course in which emphasis has been put on skills related to the use of software rather than on programming skills. A major factor in the decision not to focus on programming is the availability of other means by which students can become proficient in programming languages. Students who wish to learn programming or to become more proficient than they already are can take a variety of courses offered by the Physics Department.

The content of the "Introduction to Differential Equations" course, which is offered to the sophomore physics majors in the Fall Semester, covers ordinary differential equations, power series solutions, systems of linear differential equations, formal theories of linear differential equations, and the Laplace Transform. It lasts 12 weeks and has an attendance of about 70 students. At the end of every week, concise lecture notes are posted in the course's web-site. The web-site related activities constitute an aspect of the course which can be done without. If the student decides that he/she wants a 'traditional' coursework, the student can proceed as he/she wishes; class lectures, tutoring, homework assignments, final exams take place 'as usual'. Above all, what the student interest and involvement indicated (see Table 2 for students' opinions), was their *voluntary* interest and involvement to learning through the new technologies. The web-site comprises lecture notes, solved problems (applications of differential equations to physics and real-life problems,) homework assignments, animated interactive demonstrations, and the on-line (web-based) differential equation solvers (in which the student assign numerical values to the parameters of the differential equations,) which solve and visualize the solution. The assigned problems are similar to the problems that appear in the new generation of introductory books on differential equations, i.e., Lomen and Lovelock (1996), Borrelli and Coleman (1996), Rice and Strange (1994), Braun (4^{th} edition; 1993), and Strogatz (1997), as well as in the somewhat "older" ones, i.e. Shive and Weber (1982).

1. Predator-prey problems; shark population in the Mediterranean Sea during WWII
2. War in the Balkans (an interactive application of Lanchester's combat model)
3. Stability of a floating body
4. Non-linear energy transfer in organic systems
5. Ocean-atmosphere dynamic coupling in the Tropics
6. Evolution of a star
7. Richardson's model of conflict
8. Population dynamics of bugs
9. Earth's population dynamics
10. Greece's population dynamics
11. Authenticity of paintings
12. Epidemiology
13. High-altitude free fall
14. Water-leaking buckets
15. Internet-users population dynamics
16. An atomic waste disposal problem
17. The battle of Iwo Jima
18. Using mathematics to understand HIV immune dynamics
19. Euler's three body problem
20. Applications of the logistics equation
21. Two-dimensional motion with air resistance quadratic in the speed
22. Tacoma-Narrows bridge failure
23. A simple non-linear oscillator
24. A simple model for the detection of diabetes

Table 1: student projects

For the term-projects, students can select, voluntarily, problems of interest to them. The projects are of sufficient difficulty that it required more than a simple homework solution. One project involved the combination of a multimedia authoring tool with a programming language in order to create an interactive game (on-line). Table 1 presents the projects taken by the students during the Fall '96 Semester. The reports of these projects have been posted on the course's web-site (in greek; at http://www.physics.uch.gr/~diffeq.) These web-based reports enrich the course material for the students to come as well as the continuing education of the practicing high school teachers who can remotely access the course's web-site.

It should be noted that the students can access the materials by logging-in remotely or through one of the computers available for student use in the computational laboratory of the Physics Department (20 in total). The class of '97 statistics and the students' opinions (as registered in a questionnaire which was distributed to them during the final exam) are presented in Table 2:

ENROLLMENT: 68 students (43 passed, 25 failed)
NUMBER OF STUDENTS TAKING PROJECTS (VOLUNTARILY): 40
(of these students, 32 passed, 8 failed)
DID STUDENTS CONSIDER THE WEB-BASED MATERIAL USEFUL?
Yes: 41
No: 16
No answer: 5
DID STUDENTS CONSIDER PROJECTS HELPFUL TO THEIR UNDERSTANDING?
Yes: 66%
No: 21%
So-and-so: 5%
No answer: 8%
STUDENTS LIKED:
Interdisciplinary problems: 47%
Student collaboration: 29%
Posting the project report to the web-site: 16%
Opportunity to research: 50%

Table 2: Class Statistics and Students' Opinions

We are currently in the process of creating a CD-ROM, on the course's material, as a stand-alone educational tool (which will be handed to the students in the beginning of the semester) to enable the student to be an active participant to his or her own learning. We have designed four *Rooms* (the *Classroom,* the *Library,* the *Applications Room,* and the *Computer Room,*) where the student can navigate through and "explore" differential equations from different points of view.

5. CONCLUSION

Teaching differential equations should focus on improving the knowledge structure and the problem-solving ability of physics. This objective can be achieved by immersing the student in an educational environment where he or she will integrate principles, concepts, and procedures. The main intent of our educational effort at the Physics Department of the University of Crete, is to highlight the role of concepts and procedures in problem solving and in doing so to counter students' tendency to rely on formulaic problem-solving approaches.

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7. BIOGRAPHIES

George P. Tsironis was born in Athens, Greece, on October 12, 1958. He studied physics at the University of Athens (where he received his B.Sc. degree in 1981) and University of Rochester (Rochester, NY, USA) where he received his Ph.D. degree in 1986. He worked as research associate at the University of California at San Diego (1986-1989) and the Fermi National Accelerator Laboratory (1989-1991). During 1991-1995 he was assistant professor of physics at the University of North Texas (Denton, TX, USA). Since 1994 he has been associate professor of physics at the University of Crete, Greece. His main interests are in the areas of nonlinear dynamics, statistical physics, and the study of chaos. He has also been experimenting with new modes of physics instruction including multimedia and the world-wide-web.

George Neofotistos has recently joined the Lambrakis Research Foundation (LRF; in Athens, Greece) where he is managing, as assistant manager, the ESPRIT MENON Project (the European multimedia support network for education.) Before joining LRF, he was with the Physics Department of the University of Crete (1996-1997), the Greek Army R&D Center (1994-1996), the Florida Institute of Technology (1991-1994; Melbourne, FL, USA; assistant professor of physics), and Temple University (1990-1991; visiting professor of physics). He got his Ph.D. degree in physics from Temple University in 1989 and joined the Electrical Engineering Department of Purdue University as a postdoctoral research associate (1989-1990).