Project Links:
Interactive Web-Based Modules for Interdisciplinary Engineering Education

http://links.math.rpi.edu/

Robert L. Spilker, ASME Fellow
Professor and Chair
Department of Biomedical Engineering
Rensselaer Polytechnic Institute
Troy, NY 12180
spilker@rpi.edu

Mark H. Holmes, ASME Member
Professor and Chair
Department of Mathematical Sciences
Rensselaer Polytechnic Institute
Troy, NY12180
holmes@rpi.edu

Kenneth S. Manning, ASME Member
Adjunct Associate Professor
Core Engineering
Rensselaer Polytechnic Institute
Troy, NY12180
mannik@rpi.edu

Dianna L. Newman, Associate Professor
Educational Psychology and Statistics
University at Albany
Albany, NY 12222
dnewman@uamail.albany.edu

Project Links, a 5-year NSF-supported project at Rensselaer as part of the Mathematics Across the Curriculum initiative at NSF, is a cooperative effort by faculty from several departments, schools, and institutions to develop materials linking mathematical topics with their applications in engineering and science. The primary product of this effort is a set of interactive, web-based learning modules that rely heavily on hypertext, animations, and interactive Java applets.

Abstract

We employ interactive web-based modules in the studio classroom environment, pioneered at Rensselaer, to engage students in guided learning. The intent is to provide students with an experience unavailable in traditional lecture or textbook lessons. These modules are designed for use in more than one course, with a topic-qualified instructor and assistant available in the classroom during use. They are not intended as self-paced learning modules, nor as text replacements, but are to supplement existing courses with a degree of interactivity and universality not available before the advent of the World Wide Web.

There are currently 47 modules in development. Three modules and a subgroup of several modules of particular interest to engineering educators are highlighted in this paper. These include Drag Forces, Constrained Optimization, Mass Transport, and the Mechanical Oscillations subgroup.

A Project Links module is a self-contained conceptual unit intimately linking a fundamental mathematics topic with its application in a science and/or engineering course. Most modules have both a mathematics and an applied subject professor as developers, and are targeted for use in at least one course in each area.

I. Introduction

Project Links is a five-year, NSF supported undertaking to develop web-based interactive modules that integrate mathematical concepts with contemporary topics in science and engineering. The project is based at Rensselaer Polytechnic Institute, with collaboration from the University of Delaware, Virginia Polytechnic Institute, Hudson Valley Community College, and Siena College.[1]

These modules are to be used in a studio setting, with an instructor present, and with student access to the Internet. The modules are topic-specific, intended for use over one to three days in the normal course of the term. They rely heavily on hypertext construction, animations, interactive Java applets, and students in small group interaction. Most questions and examples are purposely left open-ended to encourage teamwork and self-discovery. The intent is to supplement existing courses, not independent study away from the classroom, though parts of a module may be assigned that way as follow-up.

The examples used in the modules are based on real-world situations. To achieve this, the module developers must incorporate experimental results, demonstrations, or design problems. Our modules use videos, real-time experiments run over the web, animations of experimental results, computer simulation, and data-reduction.

I. Background

Many forces are coming together to alter the methods used to teach today's students in the technical fields. Many years ago new multimedia tools became available that allowed those with the time, talent, and the hardware to produce innovative teaching methods. Use of many of these new ideas was limited because of the difficulty inherent in purchasing and transporting equipment that was not commonly found in the classroom.[2] At that time, however, multimedia essentially meant the use of videos, simple computer animations, and possibly some hypertext documents resident on a local computer.

Now, with the advent and unprecedented popularity of the World Wide Web and laptop computers, multimedia-based educational methods have come to mean something entirely new. Several post-secondary courses are based wholly on presentation via CD-ROM in a laptop environment.[3]

As educational learning theories progress, more effort is being applied to the introduction of collaborative learning[4] and interactive learning[5] in the engineering classroom. This fosters teamwork and personalizes feedback for the students.

Project Links, known formally as "Mathematics and its Applications in Engineering and Science: Building the Links", was conceived to intimately tie (or link) crucial topics in mathematics with one or more corresponding areas of contemporary application in engineering and science. It is funded under the National Science Foundation initiative "Mathematical Sciences and Their Applications Throughout the Curriculum"[6].

The four main objectives of Project Links are:

1. To stimulate greater cooperation in educational development among faculty in mathematics and other disciplines.

2. To encourage interactive teaching and learning strategies and to produce instructional materials for use in workshop or studio-type courses.

3. To create a library of interactive learning materials that link topics in mathematics with applications in engineering and science.

4. To continue Rensselaer's pioneering efforts in the application of contemporary technology for educational purposes and to encourage the widespread distribution of the results of these efforts.

Our approach has been to produce instructional modules that exploit the Internet and its attendant technologies of the World Wide Web, including the Java programming language. These modules are designed to be used in a studio classroom[7], with an instructor present, with significant student-to-student interaction, and with many open-ended challenges included. Project Links modules are not intended to replace textbooks, professors, or entire courses. They are meant to allow flexibility to the instructor in their efforts to emphasize certain well-contained topics that are a one- to three-day part of a regular course.

Ideally (though not always in practice) each module is developed by a team of at least one mathematics professor and one science/engineering professor, for use in a mathematics course and a science/engineering course. The Project Links Technical Office supplies these interdisciplinary teams with Internet expertise, programmers, and guidance.

The educational efficiency of the Project Links modules is assessed by the Evaluation Consortium of the State University of New York at Albany. This group has standardized the process for module development and documentation, and has developed and is implementing the evaluation plan. The consortium conducts three levels of testing: classroom observation, educational technology, and student usability. Each of the three is described in detail at the Project Links Web site.

The modules currently under development are shown in the appendix. Three modules and a subgroup of several modules of particular interest to engineering educators are highlighted in this paper. These include Drag Forces, Constrained Optimization, Mass Transport, and the Mechanical Oscillations subgroup.

II. The Project Links Web Site

Every module in Project Links has the same basic format. Shown in Figure 1 is a representative front page; this one is from the Drag Forces module. There are three standard modes of navigation through a module.

Shown marked with a **1** in Figure 1 are the PRIOR/NEXT arrows. These follow a sequence preset by the module developers. This is the path through the module the developing professors recommend in normal use. This is akin to the chapter sequence chosen by a textbook author. This sequence can be entered at any point, but is not visible to the user. The sequence will be part of the preparatory materials made available to the instructor using the module.

Marked **2** in Figure 1 is the side navigation bar (known as the "side navbar"). This is a clickable list of the main module topics and sub-topics. Each of these may also be reached when using the PRIOR/NEXT buttons, but this side list allows the user to jump around, as one would skip through parts of a textbook. A triangular icon appears next to the current topic shown in the main frame. None is shown in Figure 1 because this figure is an introductory page. This page can always be reached by clicking "Module Home" at the bottom of the side navbar.

In Figure 1, area **3** is the top navbar, used to branch off of the main topic areas listed in area 2. There are five choices here, available to the developer during design of the module. They are "Concepts", "Discover", "Applications", "Collaboration", and "Practice". Any or all may be used from any one page. Again, a small triangular icon appears next to the current branch, available choices are in bold blue, and those unavailable from the current page are grayed-out. "Concepts" are main topics, usually those that appear on the side navbar. "Discover" pages lead to questions or exercises that allow the student to explore a new area with information acquired from the "Concepts" pages. "Applications" are current uses of the topic in real-world situations. "Collaboration" supplies challenges that must be solved with a partner or by discussion between groups, perhaps with instructor guidance. "Practice" contains problems that the student must answer to allow the professor to assess the learning that has taken place. These can have the style of pencil-and-paper worksheet problems, applets, or electronic form submissions.

III. Project Links Modules

a. The Drag Forces on Solid Objects Module[8]

In this module, simple differential equations are used to study the effects of the drag force, which slows the motion of a body moving through a fluid. In this case the fluid is air, and this air resistance is responsible for the safe landing of a skydiver. This module is a part of our set of Calculus modules, and would be appropriate for use in courses in Differential Equations and Fluid Mechanics. Use could also be found in Physics and Dynamics courses.

This module leads the student through an exploration of the physics involved in objects falling through both a vacuum and a fluid by applying a force balance. There are several QuickTime[9] video presentations to illustrate the nature of falling objects. An innovative Java applet allows students to predict the velocity-time and acceleration-time curves for a skydiver in free-fall subject to the effects of air resistance. The students first sketch in their predictions, then run the applet to compare those to the answer. Probing questions allow the student to reinvestigate their ideas and make another attempt. This applet is used again later, with the parachute deploying in mid-fall.

One of the most popular features is the applet that allows students to choose two from among several types of objects, whether they fall in a vacuum or a fluid, and what the drag coefficient is. The objects are then released to fall, and their respective v-t and a-t graphs are plotted during the fall. The student then can directly compare the effects their choices have made on the rate at which an object falls.

The main part of the module concludes with an experiment of a bob falling in a tube, with the students doing the analysis first without, and then with, drag included. They are led through the analysis, breaking at several points to discuss ideas with classmates before continuing. A brief treatise on dynamic similarity is included.

The module ends with some answers and hints to the questions posed throughout in the "Collaboration" and "Practice" sections.

b. The Constrained Optimization Module[10]

This module, part of the Advanced Math Methods group, helps the students grasp the principles of optimization of multivariable functions with equality constraints. This is done with the use of geometric experimentation.

Students examine the geometry of navigating in a plane, and translate those geometric ideas into the language of calculus. They then reformulate the navigation problem as a problem in calculus and attempt its solution. Extensive use is made of graphical solution techniques through Java applets.

Later in the module, students construct a mathematical model of the output of a business, and examine geometrically the associated optimization problem. Students learn to transform geometric observations into analytical statements by extracting the mathematical principles underlying single-constraint optimization. In the later parts of the module the instructor has the option of letting students extend the optimality conditions to include multiple constraints. The module ends with practice problems and more applications.

c. The Mechanical Oscillations Subgroup

These are a collection of eight closely related modules. These are Dynamic Systems Investigation, Spring Mass, Forced Spring Mass, Linear Pendulum, Non-linear Pendulum, Spring Pendulum, Multiple Spring Mass System[11], and Vibrating Strings[12]. Together these represent the combined efforts of over 40 people. They are part of the Differential Equations Group.

The Mechanical Oscillations modules are all closely tied to experiments conducted by the module authors and their students. The Spring Mass module, one of the more mature of the collection, begins by presenting the real-life physical system and its actual dynamic behavior, using different spring mass combinations. The next step is to model the system, physically and mathematically. The behavior of the model is then analyzed using both exact formulas and numerical solutions. The final step is to compare the predicted dynamic behavior with the experimental data of the actual system and to evaluate the model's accuracy. If the predicted behavior matches the experimental data, then the model is adequate. If they don't match, then either the data collection or the modeling and analysis, or both, must be refined. This same process is repeated until the comparison is successful. The module also has a parallel track discussing damped oscillations of a spring mass system.

The Vibrating Strings module uses an interactive simulation of the vibrating string, and also includes comparison with experimental data. The module then takes the student through an interactive derivation of the solution of the wave equation for the vibrating string. Many useful links are supplied to other animations and discussions outside of the Project Links site.

d. The Mass Transport Module[13]

There are many instances in biology and in the environment in which mass transport is an important phenomenon. Everything from cellular osmosis to glucose uptake to pollution in lakes and ponds can be related to mass transport. The Mass Transport module introduces the ideas of concentration and concentration difference and formalizes how these concepts are responsible for many common phenomena. The module contains a series of related demonstrations and exercises that build on one another, allowing students an incremental understanding of the subject through increasing levels of complexity.

The module takes the student through the developmental ideas of mixing and transport in both single and multi-chamber configurations. The module addresses diffusion, transport across single membranes and multi-membrane systems, concentration profiles, and gas transfer. The module has interactive applets to illustrate the concepts and guide the students toward understanding.

IV. Summary

Project Links closely relates the instruction of topics in mathematics to the application of those topics in fields of science and engineering. It does this through the innovative use of the hypertext nature of the World Wide Web, animations, and interactive Java applets. These modules are meant to be used in an instructor-lead, studio setting. There are currently forty-seven modules in various stages of development. A consortium of experts in the field of education reviews the project with the intent of establishing educational effectiveness.

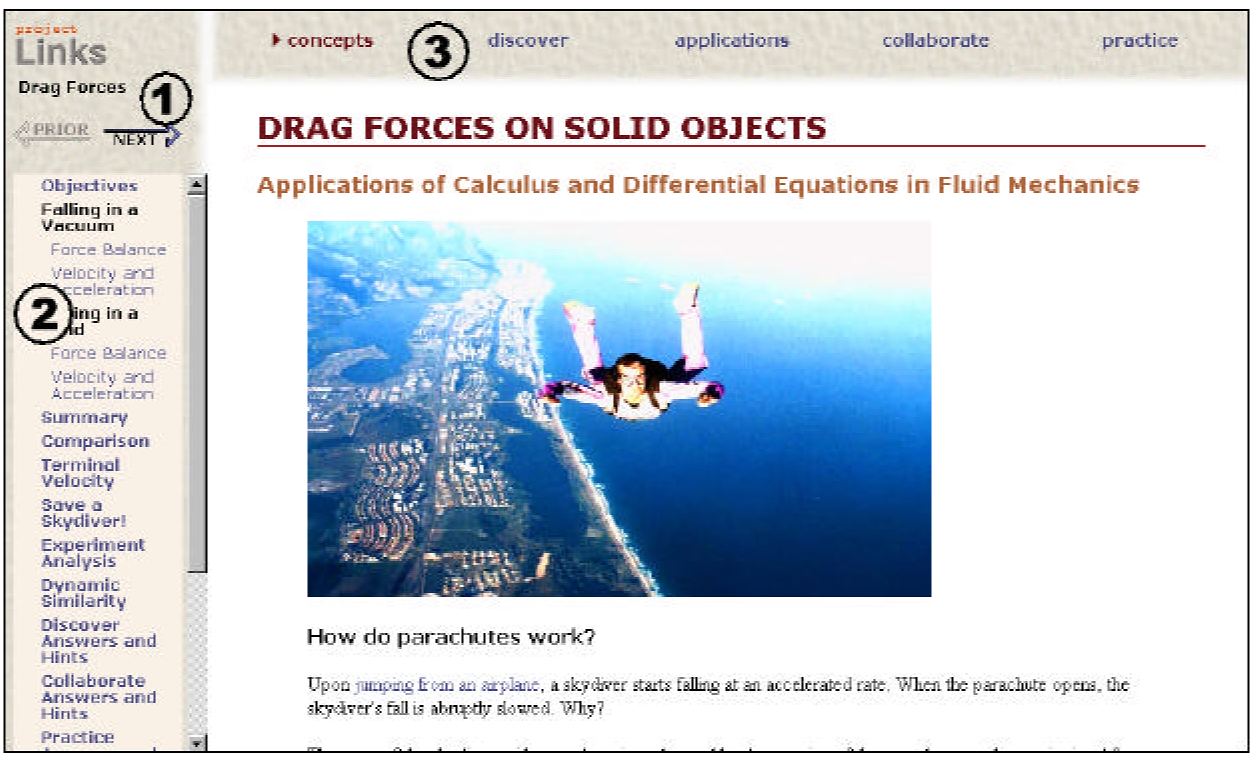

Figure 1. This is a typical module introductory page. Shown is that of the Drag Forces module.

V. Acknowledgments

Project Links gratefully acknowledges the support of the National Science Foundation under grant # DUE-9552465.

VI. Appendix

Project Links Modules Grouped by General Mathematics Topic

Calculus
- Curvature and Curve Design
- Chemical Kinetics and Equilibria
- Drag Forces on Solid Objects
- Electrostatic Field and Potential
- The Gradient
- Moment of Inertia

Advanced Math Methods
- Constrained Optimization
- Fourier Series
- Ampere's Law
- Electric Field
- Faraday's Law and Induction
- Gauss's Law
- Magnetic Field
- Maxwell's Equations

Linear Systems
- Bicycle
- Matrix Kit

Probability and Statistics
- Conditional Probability
- Continuous Random Variables
- Inventory Control
- Means and Variances
- Poisson and Exponential Distributions
- Random Variable Relations

Discrete Mathematics
- Graph Theory: Industrial Drilling
- Graph Theory: Networking
- Graph Theory: Sperner's Lemma

Differential Equations
- Boundary Value Problems for ODEs
- Continuously Stirred Reactor
- Lake Pollution
- Mass Transport
- Sequential Batch Reactions
- Dynamic Systems Investigation Process
- Forced Spring Mass
- Linear Pendulum
- Non-Linear Pendulum
- Spring Mass
- Spring Pendulum
- Vibrating Strings
- Capacitance
- Current and Resistance
- Inductance and Inductive Circuits
- Geometrical Optics
- Electromagnetic Oscillations

VIII. Bibliography

1. The Project Links Web site, http://links.math.rpi.edu/

2. Neu, E. C. "Computer and Overheads vs. Multimedia in the Classroom", ASEE Annual Conference Proceedings, 1996, Session 2220.

3. Gramoll, K. "Teaching Statics Online with only Electronic Media on Laptop Computers", ASEE Annual Conference Proceedings, 1999, Session 1668.

4. Costanzo, F. and Gray, G. L. "Collaborative Learning in Undergraduate Dynamics Courses: Some Examples", ASEE Annual Conference Proceedings, 1999, Session 3268.

5. Gray, G. L. and Costanzo, F. "Interactive Dynamics: A Collaborative Approach to Learning Undergraduate Dynamics", ASEE Annual Conference Proceedings, 1999, Session 3268.

6. National Science Foundation, "Mathematical Sciences and Their Applications Throughout the Curriculum", Program Announcements, 93-164 and 94-15.

7. Wilson, J. M., "The CUPLE Physics Studio", Physics Teacher, 1994, 32, 518-523.

8. Littman, H. and Fleishman B., "Drag Forces on Solid Objects", Project Links, http://links.math.rpi.edu/webhtml/CAindex.html, 1999.

9. The QuickTime video player, http://www.QuickTime.com/, Apple Computer, Inc., 1998.

10. Kapila, A. and Buhler, B., "Constrained Optimization", Project Links, http://links.math.rpi.edu/webhtml/AMindex.html, 1999.

11. All are Seigmann. W., Boyce, W., et. al., Project Links, http://links.math.rpi.edu/webhtml/DEindex.html, 1999.

12. Kovacic, G., Project Links, http://links.math.rpi.edu/webhtml/DEindex.html, 1999.

13. Newall, J., Manson, R., and Drew, D., Project Links, http://links.math.rpi.edu/webhtml/DEindex.html, 1999.