What is Design and How Do We Let Non-Engineers in on the Secret That it's Fun?

Charles Nippert, Antonia D'Onofrio, Stephen Madigosky, Akshay Vilivalam
Widener University

Abstract

Engineering design is often one of the more interesting and exciting aspects of engineering. Yet few outside the profession ever experience its challenges. At Widener University, an education course is offered to in service high school teachers that provides them with an opportunity to develop a Virtual Laboratory designed around standard science experiments. Programming was performed by one of the authors, while the class participated in the design process, experiencing the iterative nature of the process and learning basics of software evaluation and web programming.

The course was first offered in the spring of 2003 with an enrollment of five and again in the spring of 2004 with six participants. Both the in service teachers who participated in the design process and the high school students who tested the resulting simulations reported positive experiences.

Why is it so hard to explain engineering to people who are not engineers?

This project is based on the idea that high school students could be best informed about engineering indirectly; using the high school teachers with whom they were already in contact. We sought to make the participating teachers more aware of the engineering profession, in the hope that they would favorably influence their students toward a career in the profession.

Our course attempts to provide the teachers with the experience of participating in a design team that creates online, interactive virtual laboratories in their subject area. Creating virtual laboratories was selected as a project because we want the teachers to be active participants in a creative process that deals with a complex scientific and technical project. Therefore, the course's central topic needs to be something teachers already are familiar with. The web–based simulations created during the course are based on actual experiments performed in the in-service teachers' own classes. Initially, the subject area of the simulations was restricted to physics, so that a High School physics class at Ridley High School, which is nearby, could be used as a beta site. This restriction limited interest in the course and caused a lower than anticipated enrollment (5 students). The second year the course was offered (spring 2004), the use of a predetermined subject, such as physics) and beta site class was eliminated so that the potential subject areas for model creation could be expanded to include any science topic taught by any teacher enrolled in our course. In 2004, the enrollment was six teachers; however, the enrollment would have dropped had we not expanded the potential subjects.

The actual programming for the simulations is performed by one of the authors (Nippert) while the in-service teachers prepare additional background material that is incorporated into a web site that the class develops as a team. The education course includes several topics that are helpful to the teachers in their daily work and are aimed at stimulating interest in and understanding of the engineering profession:

1. An introduction to team based design of a science-related project (the design of a science web site)
2. A background in "Usability" as applied to software interfaces and web site design. This was key to designing the interface of the simulations.

We want the teacher to participate in the details of creating a web site s that they have the experience of creating web-based educational material. Therefore, we provide instruction in the use of Microsoft FrontPage™, a software tool used in the creation of web sites. This tool was chosen because it was already available on the campus network. Also, we want the participating teachers to be able to evaluate the large amount of multimedia material that is available for their use on the Internet.

Virtual Laboratories

Recently, much has been done to create Virtual Laboratories that can be accessed using the Internet. In physics education, for instance, Learn Anytime Anywhere Physics **(**LAAPhysics™**)*** is a physics education research and development project that is developing the open-source LAAPlatform (1). LAAPlatform provides a three-dimensional learning environment. Model Science Software offers Model ChemLab™ (2), which provides interactive simulation of chemistry experiments. Kfir (3) has described the development of a physics virtual laboratory using a method that simplified the development of multimedia materials. His aim is to enhance education in developing countries. The author's own virtual laboratories are used for junior, senior and graduate courses (4,5) and are among the many that have been created by individual instructors for specific courses. There are also many free sites containing materials available to educators; www.edinformatics.com, www.colorado.edu/physics/2000/index.pl, www.xplorelearning.com, www.jhy.edu/~virtlab/virtlab.html, and www.phy.ntu.edu provide free simulations that can be either referenced or downloaded for individual use.

The advantages of using simulations are low cost, speed of performance, ability to simulate experiments that can not be safely or easily performed in the real world and, the ability to easily accommodate a large number of multiple simultaneous users. The effectiveness of the use of simulations in instruction has been the subject of examination. Recently, Triona and Klahr (6) has investigated the effectiveness of simulations in elementary education and found that simulations may be comparable in effectiveness to actual experiments in some forms of instruction.

Internet laboratories commonly use browser plug-ins; specialized add-ons to the user's web browser that provide enhanced interactive capability. Two plug-ins that can be used in the development of virtual laboratories are the Java Virtual Machine™ and the Shockwave "Movie". The Java Virtual Machine was initially created by Sun Microsystems. The Shockwave plug-in is created by Macromedia. Both plug-ins offer the developer the ability to create materials using sophisticated object oriented programming (OOP) in high level languages; JAVA for the Virtual Machine and Lingo for Shockwave. This makes the term "movie", although commonly used to describe modules that run in the Shockwave plug-in, somewhat misleading because it creates the impression that the viewer passively watches the module. Actually, these modules are fully functional, interactive programs similar to Java applets, which the reader may be more familiar with.

Course Overview

The large variety of choices of web-based materials and the ease with which course specific materials can be developed means that teachers may use the ability to evaluate the suitability of multimedia software. Our education course attempts to provide the participating teachers with:

1. Web ready simulations of experiments that are specific to laboratory experiments actually performed in their courses,
2. Techniques and skills that will help them evaluate multimedia materials in their own courses,
3. The experience of participating in a project aimed at designing a complex technical item (software) and,
4. Skill necessary to create a small web site using a readily available software package, known as FrontPage™.

The course was first offered in the spring 2003 semester and again in the spring 2004 semester (the time of this writing). The classes met for three hours, once a week in a computer laboratory where each student had individual access to a computer and Widener's network. There were several required texts and suggested further reading which are shown in Table 1. The syllabus is available online at the author's web site (www2.widener.edu/~crn0001) and covers topics related to usability, web site design.

Table 1show the emphasis on “usability” and interface design.   These are important to the course because of the course’s focus on creating materials that would be accepted by students in the teachers’ classrooms.

Table 1
Required Texts

Microsoft FrontPage 2002 Fast & Easy, Patirce-Anne Rutledge, Prima Publishing, 2002
Usability Engineering, Jakob Nielsen, Morgan Kaufman Publishing, 1993
Web Site Usability Handbook, Mark Pearrow, Charles River Media Services, Rockland Mass., 2000

Suggested Additional Reading

Web Design
Designing Web Usability, Jakob Nielsen, New Riders Publishing
GUI Bloppers, Jeff Johnson, Morgan Kaufman, 2000
Human Factors in Information Systems, Edward Szewczak, Coral Snodgrass, IRM Press
The Humane Interface, Jef Raskin, Addison-Weskey
The Psychology of the Human-Computer Interaction, Stuart Card, Thomas P. Moran, Allen Newell, Lawrence Erlbaum Associates
Son of Web Pages That Suck, Vincent Flanders, Sybex
Web Pages That Suck, Vincent Flanders, Sybex
Web Style Guide, Patrick J. Lynch Sarah Horton, Yale University Press
Web Wisdom, How to Evaluate and Create Information Quality on The Web, J.E. Alexander, M.A. Tate, Lawrence Erlbaum Publishers

Engineering Design
The Art of Innovation, Using Intelligent Fast Failure, J.V. Matson, Penn State Press
Handbook of Usability Testing, Jeffery Rubin, Wiley
Human Factors in Engineering and Design, Mark A. Sanders, Ernest McCormcik, McGraw Hill, 1991

Additionally, each participating teacher was given their own web site on one of Widener’s servers. The participating teachers were encouraged to create their own distinctive styles for these sites. The class evaluated the sites and used their evaluations when designing the look of the virtual laboratory. The agenda for the class meetings was divided into three segments:

1. A lecture/discussion on elements of web site design illustrated by sample web pages designed by one of the instructors.
2. A hands on session in which the investigators and the graduate student assisted the teachers in using FrontPage to create and maintain their web sites. The graduate assistant, Akshay Vilivalim, was especially helpful during this portion of the class period; providing specific and detailed guidance to the participating teachers
3. A brainstorming session in which the investigators and the teachers worked together to design the online interactive simulation of a real world laboratory experiment.

The team-based nature of the approach makes training the teachers in computer programming unnecessary. The class creates a specification for a simulation consisting of a storyboard of action and a sketch of layout in the browser window. The specification is created in class on a blackboard during a brainstorming session. The storyboard consists of the sequence of users' actions, a description of software animations and software responses to user actions. The level of detail in the storyboard and layout varies greatly; in the beginning of a course, it is often vague and general, as the course progresses, it becomes more focused and clear. One of the authors (Nippert) then creates the simulation.

The development of the class's web site is the class' goal. The web site consists of simulations and the information related to the simulation collected into a module consisting of information related to a particular real world experiment and the simulation itself. A list of tasks and assignments is shown in Table 2

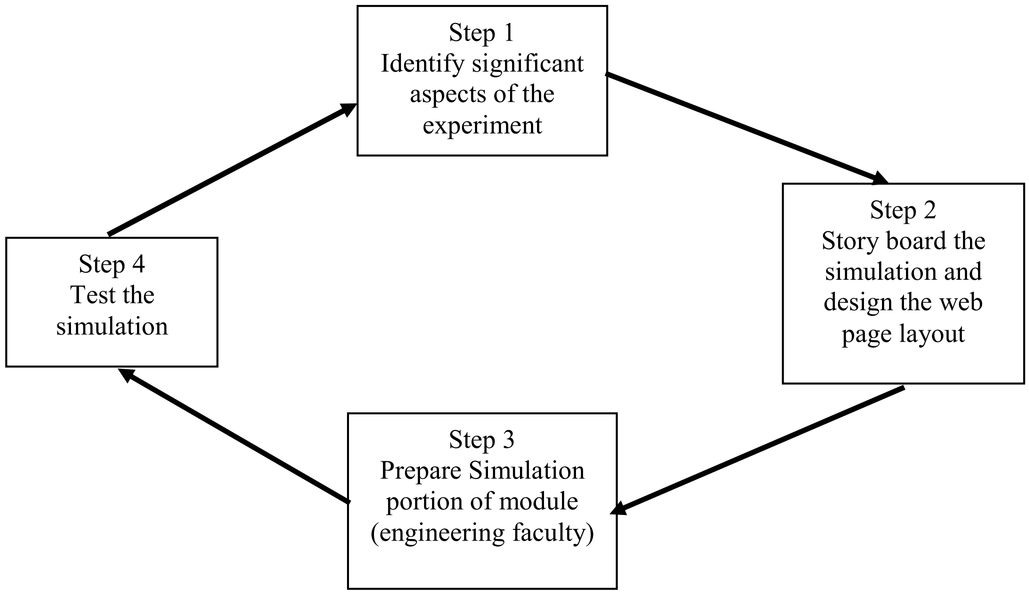
Table 2
Tasks for Creation of a simulation and web site

Simulation	Performed by:
Determine the layout of simulation on browser window (i.e. physical appearance)	Class at "brainstorming session"
Determine story board (what happens, and when)	Class at "brainstorming session"
Write simulation	Instructor (Nippert)
Revise the simulation ("close the loop" during the design process.	Class after examining the working prototype
Web site	
Create background information and content related to the experiment	Individual class members
Create layout for the web site	Class, after evaluating individual web sites

Constraints or limitations, are parts of any design project. The class has to deal with several constraints that limited their design. The finished simulation has to be conveniently accessible through a dialup Internet connection. This constraint might seem arbitrary because the beta site class at Ridley High School was connected to Widener through a high-speed connection. However, we want the finished web site to be available to students from their own home computers. This constraint effectively limits the size of the finished Shockwave movie to a maximum of about 70K. Another constraint was that a working draft of the simulation had to be written within a week so that the class could view a working prototype.

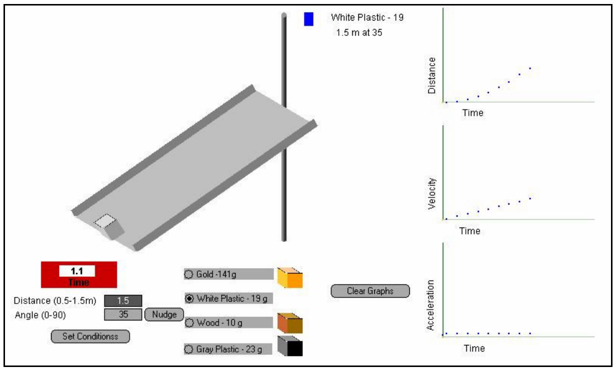
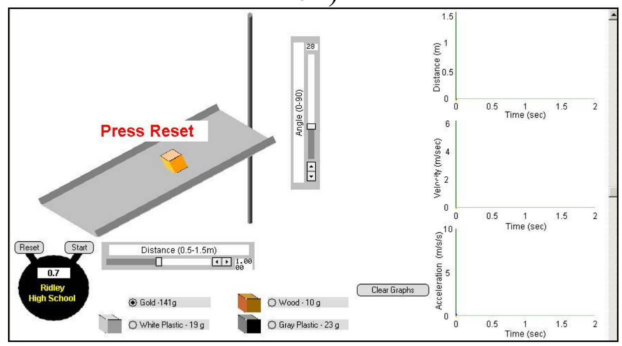
The development of a typical simulation of an experiment spanned several weeks, with a new version of the simulation each week. The process followed the cyclical approach shown in Figure 1. Anecdotes from the class indicate how experiential learning was used to teach this point.

Figure 1
Design of Modules for Instructional Web Site



The first version of the Force Table experiment was written to the specifications of the class. However, once the class operated the module, the class immediately recognized the need to change the user interface that they had designed. The evolution of another module further illustrated the design process. In this simulation, a small block slides down an inclined plane. The movement of the block is retarded by friction. Students use a stopwatch to measure the time for a block to slide a measured distance down an inclined plane of known angle. Screen shots of the first and second versions of the simulations are shown in Figure 2. During the review session, it was mentioned that a major source of error and frustration was that high school students do not always operate the stopwatch correctly. They often forget to press the stopwatch's reset button, causing incorrect times to be recorded. We replaced the digital readout in the first version of the simulation with a cartoon "stopwatch" that imitated the functionality of a real stopwatch. In the final version, pressing "Start" before pressing "Reset" causes an error message to appear and the block does not slide down the plane. In this way, the class created a design that attempted to encourage high school students to correctly use the stopwatch.

Figure 2
Screen Shots of the First Version and Final Version of a Simulation

Screen shot of first version of the "Inclined Plane"	Screen shot of the final version of the "Inclined Plane" (note the cartoon stopwatch in the lower left)
	

The Virtual Laboratory

The simulations created are also available to others (http://quantum.soe.widener.edu:302). It is possible that these materials may be useful to others. The simulations created during these courses are a summarized in Table 3.

Table 3
Experiments Simulated or in the Process of Being Simulated

Experiment	Specific Concept	Subject
Force Table	Force Balance, vector addition	Physics
Inclined Plane	Friction	Physics
Acceleration of a Cart with Masses	Newton's second law	Physics
Bullseye! (predicting the location of impact of a projectile)	Projectile motion	Physics
Teeter totter	Torque	Physics
Rocket Launch (simulates a powered rocket)	Projectile motion, sources of experimental error	Physics
*Determine genotype for the phenotype of fly offspring	Genetics	Biology
*Enzyme activity	pH dependency of enzymes	Biology
*Determine the Molarity of an unknown	Titration	Chemistry
*Wave tank	Wave phenomenon	Physics

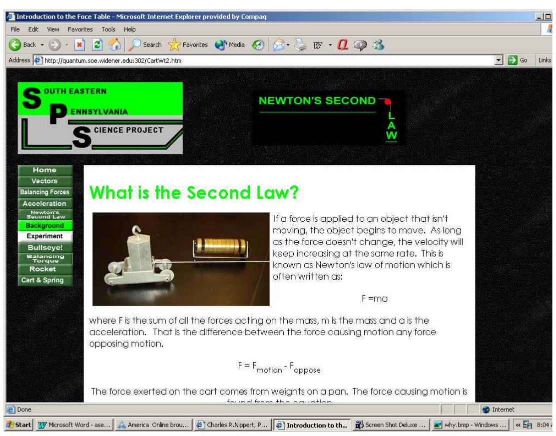
* These simulations are part of the 2004 course and are in progress at the time of this writing.

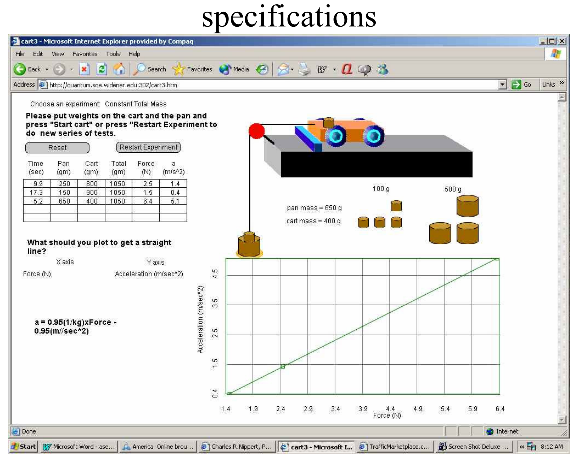
In 2003, each simulation was part of a module that has information about the concepts illustrated in the experiment and how those concepts relate to everyday life. The look of the web pages (arrangement of links, etc.), the content (text and photos) of each page and the arrangement of the content into pages was done by the students in the class, working as a team, after reading assignments, lectures and evaluating prototypes prepared by each student on their own site. Each module is introduced by a "who cares?" page that explains the relevance of the concept to every day life. More detailed descriptions of the concepts are provided on additional web site pages. Instructions for the experiments were not included in the web site because it was felt that the laboratory manuals used in the class would be adequate. Feedback from the beta site class at Ridley High School however, indicated that high school students had a strong preference for on line manuals. Sample screen shots of some web pages are shown in Figure 3.

Figure 3
Virtual Laboratory Components

Screen shot of Background information developed by Spring '03 class

Screen shot of Cart and Weights Simulation Developed in Spring '03 to class specifications





Outcomes

Insofar as there were only a few participating teachers (five in 20003 and six in 2004), it was possible to make use of qualitative methods to investigate perceived consequences of the project, both positive and negative. Open-ended surveys and participant observation were used to determine how science scholars benefited from the project. Because of the small number of students involved, quantitative results are inappropriate.

Survey findings.

- The participating science teachers indicated that there were NO unhelpful aspects of the course. They described their accomplishments in terms of learning how to build web sites and mastering FrontPage. They gave high grades to the experience of working in a group to create finished products.

- They found FrontPage difficult and frustrating initially; and believed that extensive opportunities for questions and feedback were important to eventual mastery of this software tool.
- Having a project based approach, they believed was important to their eventually success.

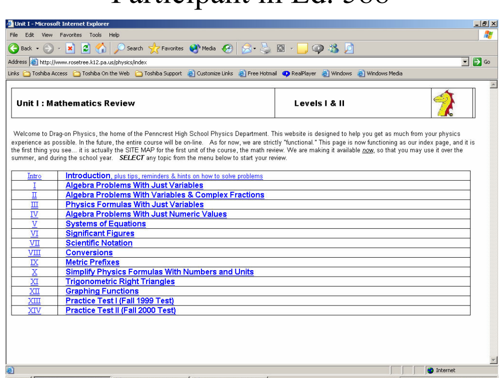
Teacher outcomes

Specific outcomes related to the integration of web technology with instruction were also cited by the science teachers.

- They described the virtual labs (and the construction of web sites) as the building of an interactive bridge to traditional aspects of instruction (such as the course syllabus).
- They suggested that students at every level of ability would benefit from the uses of web sties.
- They saw web sites as extremely functional because a wide range of course materials and teaching/learning activities could be organized within a single web site.
- They compared their newly acquired skill to a means to achieve greater accountability because their ability to develop web sites afforded them more autonomy in the design of instruction.

Anecdotal evidence revealed that the science scholars were disinclined to use the Internet as part of their regular classroom instruction because of the impermanence of the content. Fear that web site content would change was cited as a reason for not developing detailed, specialized lesson plans around such content. To mitigate this concern, our solution was to provide the scholars with a CD containing the web site that they could mount on their schools' servers. An interesting outcome was the independent transfer of the course learning to an individual participant who used the information to develop his own instructional web site. A screen shot of this web site is shown in Figure 4.

Figure 4
Screenshot of Math Review Site Developed Independently by Robert Malkowski, a Participant in Ed. 588



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6. Triona, L.M.; Klahr, D., "Children's developing the ability to create external representations. Separating what information is included from how the information is represented", Proceedings of the Annual Conference-Cognitive Science Society, 2002, p. 1044

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Charles R. Nippert
Prof. Nippert has been on the faculty of the Chemical Engineering Department of Widener University, Chester Pa. since 1980.). His current interests include process simulation, process control and the development of web-based instructional materials for use in a variety of engineering and education courses. More information can be found at his web site, "www2.widener.edu/~crn0001". He is married and has two children.

Stephen R. Madigosky
Professor Madigosky holds a joint appointment between the Biology and Environmental Science Departments and the Center for Education at Widener University. His research interests include environmental toxicology, tropical micrometeorology, and science education reform. Professor Madigosky helped develop the Science and Education Standards for the Commonwealth of Pennsylvania.

Akshay Vilivalam
Akshay Vilivalam is a graduate student in the Chemical Engineering Department of Widener University. He also holds a Masters Degree in Computer Science from Villanova University. His research interests are in computer simulation and Process Control.