The Physics 2000 Project: Interactive Physics on the World Wide Web

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What is the Physics 2000 Project?

Created by leading researchers, the Physics 2000 Project has generated an innovative interactive Web site[1] designed to make modern physics and technology accessible to K-12 students, college students, and the general public. A key element in the success of this ambitious project has been the use of Java applet technology to create over 35 "virtual experiments" that are controlled using the computer mouse. By combining graphics primitives, concurrent threads, and GUI input events, Java permits rich inter-active animations to run locally on Web clients.

Users of Java-enabled Web browsers such as Netscape 3.0 find their screens transformed into a laboratory containing experiments ranging from an X-ray fluoroscope[2] and CAT-scans[3] to interactive laser and magnetic-evaporative cooling[4] for creation of the Bose-Einstein condensate. This "virtual" laboratory has certain advantages over real laboratories. It allows the user to see the physics concepts as they are visualized by leading scientists. These dynamical visualizations convey far more than static text, or even a real experiment. Interactivity further enhances the learning experience.

For example, when charges are shaken (using the mouse), the users see how the electric lines of force wiggle[5] and an electromagnetic wave is launched. The frequency can be varied and the user notes that this affects the wavelength. An option to derive the algebraic relation among wave speed, wavelength, and frequency is offered. In another applet, users shine different colors of light on an atom and observe how the electrons change in energy and position. These and other interactive virtual experiments are demonstrated in this paper.

The interactive demonstrations are unusually tactile and responsive, as well as just plain fun. This makes the science as concrete and intuitive to the student as it is to the seasoned researchers who designed the site. The subject matter is primarily 20th century science and technology. Devices such as X-ray machines and microwave ovens lead into explanations of electromagnetic waves and how they interact with matter. Recent exciting research discoveries such as Bose-Einstein condensation and novel quantum interference are also featured.

In addition to virtual experiments, other pedagogical strategies are used to enhance the presentation. Dialogue between cartoon characters provides exposition into which the virtual experiments are embedded. By proceeding from familiar technological devices to the more abstract underlying concepts, the physics is made relevant to the non-scientist. Various levels of complexity are incorporated through the hypertext format so that users can easily select the level that matches their background and interests. The cartoon characters serve to identify the level of difficulty of the subject matter. Workshops with high school teachers have been employed to evaluate these strategies and useful feedback was incorporated into the Web site.

The Web site has received considerable recognition. It has been endorsed by the American Physical Society and the Exploratorium in San Francisco, and it has drawn favorable responses from educators, students, and users from around the world. Future development will include units on lasers, compact disc players, microwave ovens, molecular bonds and basic chemical processes, particle accelerators, thermonuclear fusion, and many more.

The innovative form of presentation transcends the traditional divisions of "elementary" and "advanced" concepts and topics, which form the foundation upon which most physics curricula are built. As it expands to cover more material, this project should be a valuable educational resource for science teachers and students at every level.

How Did the Physics 2000 Project Get Funded and Managed?

The Physics 2000 project was originally conceived as an in-class resource to be used in conjunction with innovative undergraduate physics courses for non-majors. Support for the project was initially sought from the undergraduate curriculum division of the National Science Foundation (NSF), but a proposal for seed money was turned down. The focus of the project was then broadened to include outreach, especially to K-12 educators throughout Colorado. A proposal with this new emphasis was sent to the Colorado Commission on Higher Education (CCHE). In addition to development of a Web site, the proposal provided for a sequence of workshops to be held with local and statewide educators. The proposal was approved, and a generous level of support was furnished by CCHE for 18 months. This grant ended June 30, 1998. At present, we are seeking support to continue for another three years. Once again, we are going to NSF, but to a different division. We are also seeking to secure corporate support through the University of Colorado Foundation.

The grant from CCHE enabled us to hire a cadre of artists, designers, cartoonists, HTML formatters, and programmers to create a unique and highly professional technical staff. In addition, graduate students and undergraduates were hired. A group consisting of these personnel together with faculty from the Physics and Chemistry Departments at the University of Colorado met weekly to discuss strategies and review the progress of the Web site. In between these meetings, a student (graduate or undergraduate) would typically meet with a professor and our programmer, David Rea, to develop a flow of pages in the Web site devoted to a particular topic. Once the general flow of information was established, both faculty and students wrote dialogue for our cartoon characters. Often a particular Java-applet “virtual experiment” drove the dialogue. In general, dialogue was felt to be the best form of exposition for the Web, since it nicely parses the information into a few sentences at a time that can be easily read on the screen.

What is So Unique About the Java Applets on This Web site?

One of the effects we have striven for in our applets is tactility: the illusion of physical reality in the graphics. Based on both observation of students and personal experience, we have found that simulations that look more real are also more engaging. The computer game industry, obviously, has discovered the same thing.

For the most part, tactility in Physics 2000 is accomplished through entering the third dimension. That is, we attempt wherever possible to step beyond flat, monochromatic graphics and instead use shaded 3D objects, whether in the spheres and arrows we use to represent particles and vectors or the buttons and sliders we use for controls. Liberal use of drop shadows (even for some objects, like electrons, that don’t really have shadows) further enhances the illusion.

The major drawback with these techniques is in loading time, as they often require extra images to be imported over the net. Loading times can be minimized with the use of JAR formats, but so far we have avoided this approach because of the scarcity of JAR compatible browsers.

Another important component in achieving tactility is to design applets in which the user interacts with the simulation itself, rather than merely adjusting sliders and pressing buttons. Although this approach is not always practical, we try to use it whenever possible because it makes the objects feel even more real. Furthermore, screen controls almost always imply a finite number of possibilities for the applet, while interaction with the components themselves vastly increases the variability of the simulation. Pedagogically, this leverages the same advantage that a Lego set has over, say, a toy truck or plane. Flexibility encourages experimentation and thus extends engagement.

Java was pretty much the only language choice for Physics 2000, given our requirements for multi-platform compatibility and integration with the Web. However, it is worth mentioning a few of Java’s strengths and weaknesses. Perhaps Java’s greatest asset is its smooth handling of graphics. It is a relatively simple process to import transparent GIF images and animate them, creating rather complex simulations with minimal effort. In addition, Java makes it extremely easy to convert between images and integer arrays, allowing for a variety of algorithmic image manipulation. Although the language itself supports alpha (transparency) channels, current implementations don’t support intermediate alpha values, only complete opacity or transparency. However, the ability to generate non-rectangular images is very useful.

Ignoring for now the bugs in various Java implementations, the single greatest limitation in Java is the inability to graphically step outside the bounds of the applet to draw on the surrounding Web page. In other words, when you define a region for the applet on the Web page, the applet is not only stuck within those confines, but also text or images from the page can not intrude inside that region. Changing this design flaw with the addition of just a few methods in the Java language would not only allow much more visually interesting effects, but would also save significant page real estate. Imagine a model of the atom where the electrons fly out in huge orbits across the rest of the page. (For an example of how this would look, see the applet at:

www.colorado.edu/physics/2000/applets/newhome.html)

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Comments from users of the site:

"Your site illustrates the power of Java applets to make complex subjects come alive in a way that visitors, young and old, can understand and appreciate. I hope that you and your team will be able to create more experiences of this quality in the future."

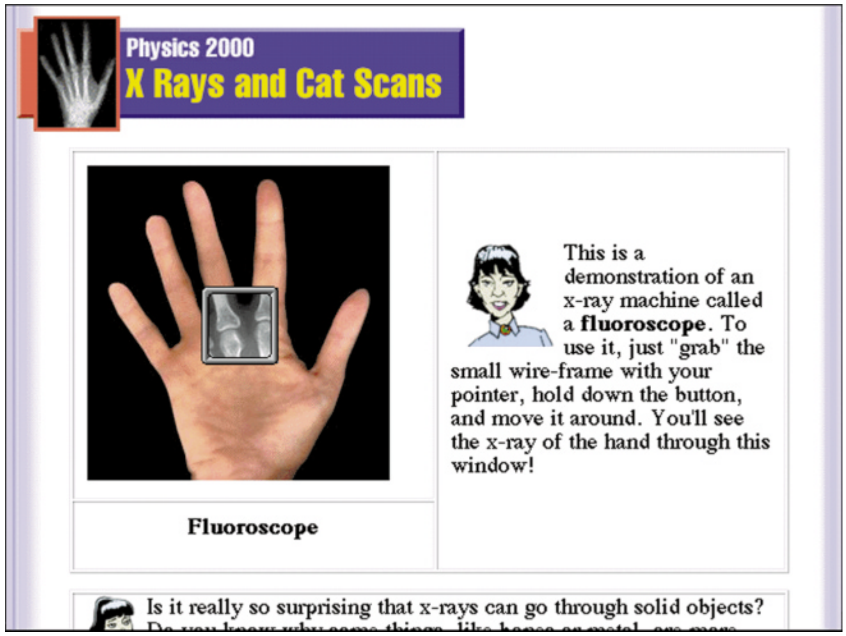
Ramon Lopez, Director, Education and Outreach,
The American Physical Society, Washington, DC

"I am a high school physics teacher in Highland, Illinois. This site is terrific. I have been looking for some way to use the computer to enhance the learning process, but I have found that most programs and sites seemed to be unfriendly and inaccessible. This site is fantastic! I can't wait to let my students know about the site and have them begin to explore for themselves. Keep up the good work. Thanks for your hard work!"

Cliff Parker

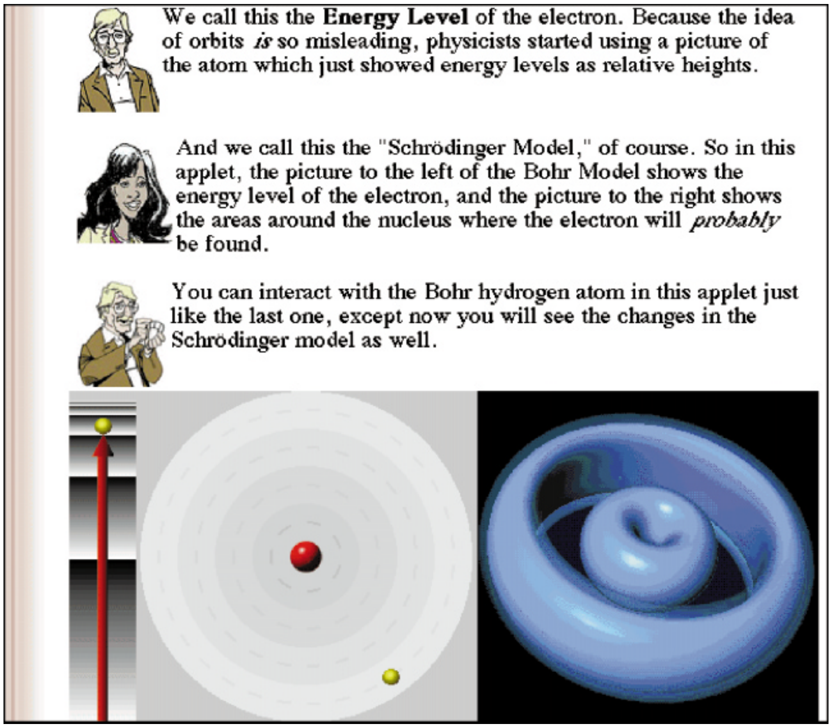
"I'm a second-year student at the University of Michigan, and I'm currently taking a course in 20th Century Concepts of Space, Time and Matter. My professor put links on his own Web page to your Web page, and I've found it to be extremely helpful. I think it's creative and instructive at the same time. I never realized what a good job cartoon characters could do of teaching Quantum Physics! Thanks for your help!"

Peter Handler

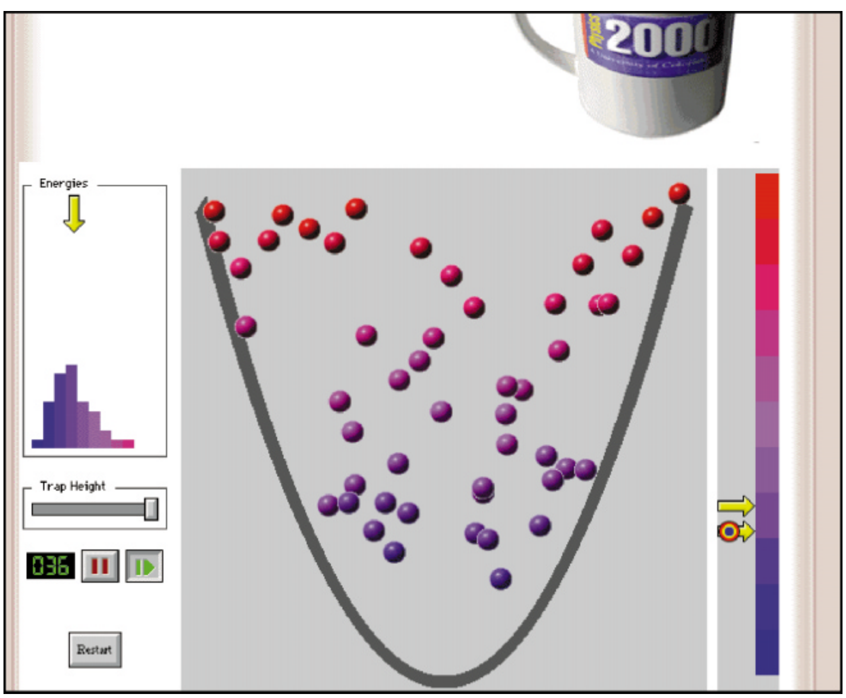


Fluoroscope applet. (A tactile applet for all ages.)

1 www.colorado.edu/physics/2000
2 www.colorado.edu/physics/2000/xray/index.html
3 www.colorado.edu/physics/2000/tomography/x _rays.html
4 www.colorado.edu/physics/2000/bec/index.html
5 www.colorado.edu/physics/2000/waves_particles /wavpart4.html



Schroedinger and Bohr atom applet. Click on an orbit to induce a transition involving a photon. (Modern physics applet for advanced high school or undergraduate college physics.)



Bose-Einstein condensate applet. Magnetically trapped atoms are evaporatively cooled to low temperatures, producing a new state of matter. Lower the trap height to "evaporate" the fast atoms. (A modern laboratory achievement made understandable to the general public.)