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Open Source Physics

A curriculum resource designed around interactive computer-based modeling brings computational physics to students of all levels.

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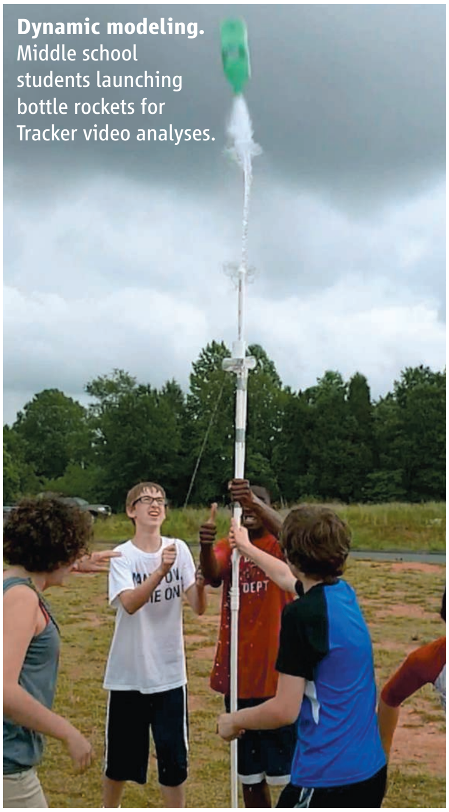
Scientists routinely use computer modeling and computation in innovative research, including predicting the nature of He^4 at extremely low temperatures and the impact of human activity on climate. Why does computer-based modeling remain absent from many educational programs?

The Open Source Physics (OSP) project, www.compadre.org/osp/, seeks to enhance computational physics education by providing a central Web site containing computer modeling tools, simulations, curricular resources such as lesson plans, and a computational physics textbook that explains the pedagogic simulations' algorithms (*1*). Our resources are based on small single-concept simulations packaged with source codes that can be examined, modified, recompiled, and freely redistributed to teach fundamental computational skills. Students at all levels will benefit from these interactive simulations by learning to question and assess the simulation's assumptions and output.

Students who learn physics concepts via static pictures may be led to construct incomplete or incorrect mental models that hamper their understanding of physical concepts. Our ready-to-run simulations and tools for developing new simulations help students visualize situation and better understand abstract concepts through a research-proven pedagogical process called the Learning Cycle (*2*, *3*).

In the first phase of a simulation-based cycle, "Exploration," students explore questions or a problem situation about a phenomenon or concept and make predictions about the outcome. This phase encourages students to think about the subject matter, become curious about it, raise questions, and use prior knowledge in the construction of a hypothesis about possible simulation outcomes. Students may then test their hypotheses using an experiment or demonstration together with a simulation. During the second phase, "Invention," the teacher guides students through the introduction and development of essential



Dynamic modeling. Middle school students launching bottle rockets for Tracker video analyses.

knowledge. Students may begin by sharing their observations and ideas from the exploration phase. The teacher then uses simulations to develop the content knowledge and to introduce relevant vocabulary. In the final "Application" phase, the teacher poses new problems or situations for the students to solve, based on the exploration that they refined in the second phase. The same simulation can be used in more than one Learning Cycle phase or can be modified and extended once teachers are familiar with the OSP computer-modeling tools.

Our simulations require student interaction. When solving physics problems, novice students tend to reach first for an equation to apply rather than trying to understand the underlying physics concepts. In well-designed simulations, physical quantities, such as force or field strength, are not given. Instead, they must be determined by running and observing the outcome and by interacting with the simulation to make measurements. By determining relevant information early in the problem-solving process, students must understand the conceptual underpinnings of the problem. Our simulations also use multiple representations to depict information, as students learn best when they see ideas presented in different ways, for example, as time-based graphs and tables (*4*).

The transition from working with interactive simulations to computer-based modeling can be especially challenging for students. In addition to learning a programming language, students must master a range of techniques, such as compiling and linking with graphics and numeric libraries, before being able to create a running computer program. To minimize these difficulties, OSP has developed a number of free modeling, authoring, and analysis tools. Two of these tools are Tracker (*5*) and Easy Java Simulations (EJS).

The Tracker video analysis and modeling tool enables students to create particle models based on kinematics or Newton's laws and to compare the model's behavior directly with that of real-world objects, such as the water rocket shown in the first photo, captured on video (*5*). Tracker's model builder provides an introduction to dynamic modeling by making it easy to define and modify force expressions, parameter values, and initial conditions, while hiding the numerical algorithm details. Because Tracker particle models synchronize with and draw themselves right on the video, students can test their models experimentally by direct visual inspection. A browser in Tracker enables users to open videos and models directly from the OSP and other Web sites.

The Easy Java Simulations (EJS) modeling tool organizes a computer model into four parts: the computation, which implements the phenomena under study in terms of variables that describe the state of a system and algorithms that change those variables; the control, which defines actions that a user can perform on the simulation; the view, which shows a graphical representation of the model and its data; and the description, which provides an opportunity for the author to document the model's theory, assumptions, and range of validity.

A typical phenomenon that is studied in introductory physics is the harmonic oscillator. A simple algorithm that teaches both the physics and calculus of harmonic motion follows:

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a = –k*x/m; compute acceleration
v = v + a*dt; advance velocity
x = x + v*dt; advance position
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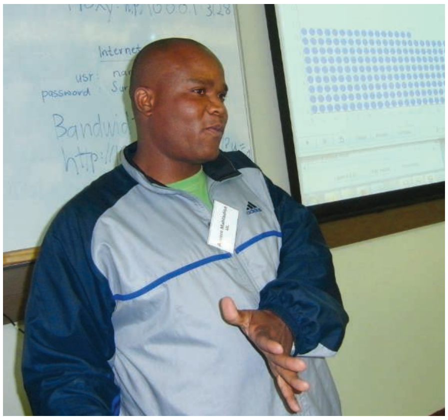
The first statement says that acceleration is caused by a spring force, the second says that the acceleration affects the velocity, and the third says that the velocity affects the position. Very little additional code is needed to produce a simulation, as the user interface is constructed by dragging and dropping buttons, graphs, and tables from a palette onto the view. Basic programming syntax is taught while students focus on implementing ideas as algorithms and on interpreting the model's output.

After a model is built, its supplemental graphics and description pages are packaged for distribution. The resulting file is a stand-alone application that does not require EJS and can run on any computer with a Java virtual machine. Because every simulation is distributed with its source code, users can examine, modify, and redistribute the model with minimal effort. Right-clicking within a running simulation displays a menu with an option to extract and copy the source code into the local computer's EJS workspace. This allows teachers to ask students to modify and repackage a model, thereby creating a teacher-student feedback loop that supports the Learning Cycle.



Skill building. A South African OSP workshop participant presenting results from a molecular dynamics model.

The OSP Web site allows teachers to pick their level of computational engagement from a range of possibilities. Teachers may use and modify existing simulations, distribute ready-to-run simulations to students for visualization purposes, distribute partially constructed or flawed models that students must edit and return, or construct broad assignments for students to create models from scratch (*6*).

The OSP Collection currently contains more than 400 primary materials, and many entries have multiple support documents. For example, the "Roller Coaster" model includes three ready-to-run simulations, a lesson plan and student worksheet, an applet page, and the source code. A tabbed panel provides annotations, including this material's alignments to the AAAS Benchmarks for Science Literacy and the National Science Education Standards. As with any good library, the documents are cataloged with standard metadata and can be found via search criteria such as subject, author, level, and keyword.

Despite its original focus on upper-level college physics, the OSP Collection serves thousands each month. During March 2011, we served 10,000+ visitors with 5000 simulations, an increase of 32% over March 2010 traffic. User loyalty is increasing as well; over 2500 different users visited at least eight times between January and March 2011, an 80% increase from January to March 2010 and an indication of the project's increasing visibility.

The OSP Web site is based on the ComPADRE Digital Library infrastructure and supports peer-reviewed user submissions of simulations and text resources, personal resource collections, and discussion forums where users can post questions and discuss lesson plans. Because ComPADRE is itself a part of the National Science Digital Library (NSDL), OSP is able to broadly disseminate records for its content to partners using standardized educational metadata. The OSP Web site also provides federated access to resources from other projects including the NSDL.

Designing and building models that intrigue and educate without overwhelming has been challenging. We have learned that a simple set of buttons to start, stop, and reset a simulation followed by a small number of editable parameters, such as the length of a pendulum, helps to guide inquiry. Additionally, we learned that "freely available on the Internet" is not enough. The process of establishing and cultivating an active international community that shares new simulations takes an ongoing commitment. Meeting face to face and developing personal relationships with faculty are essential for obtaining new simulations and have proven to be at least as important as having an attractive Web site. Thus, we give a number of workshops (see the second photo) every year for novice and expert modelers alike. These workshops help faculty to form and refine the skills needed to create simulations and implement modeling in their classrooms. For those unable to attend, we offer online video tutorials to help develop computational modeling skills.

Computational modeling tools allow students to understand a model and its computational programming rather than working on creating its user interface. Paraphrasing Richard Feynman, we have learned that if we cannot reduce a model to an algorithm, we do not completely understand it.

About the authors

Wolfgang Christian is the Brown Professor of Physics and chair of the Physics Department at Davidson College, a Fellow of the American Physical Society (APS), past chair of the APS Forum on Education, and president-elect of the North Carolina Section of the American Association of Physics Teachers. **Francisco Esquembre** is associate professor of Mathematical Analysis at the University of Murcia, Spain, and dean of its Faculty of Mathematics. He teaches mathematical analysis and numerical algorithms of continuous and hybrid systems and is the creator of Easy Java Simulations. **Lyle Barbato** is the technical director of the ComPADRE Digital Library and has developed the OSP Web site's tools and support services. Christian, Esquembre, and Barbato have been collaborating since 2005 on the development and distribution of interactive computer-based material.

References and Notes

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