The National Computational Science Institute

Shodor Education Foundation, Inc.

Educating Scientists for the Twenty-first Century

Since its founding in 1994, the Shodor Education Foundation, Inc. has been dedicated to advancing science and mathematics education through the use of computational modeling. Scientists, engineers, and educators have long advocated the use of authentic technologies in science and engineering education. The increasing importance of computational modeling in research and industry mean that it is now time to include computational science in all aspects of the undergraduate curriculum. The nation's undergraduate faculty are the *pressure points* for educational reform and improvement and must be engaged if this reform is to succeed. The creation of the National Computational Science Institute marks a new phase in expanding Shodor's collaborations to meet this pressing need.

Computational Science as Science Education

Scientists, engineers and educators have long advocated inclusion of authentic technologies in science and engineering education. These technologies are well represented in the laboratory exercises associated with science and engineering courses. Now, the tools of computational science – interactive numerical simulations, scientific visualizations, computer-assisted algebra systems and data mining – must be included in the undergraduate curriculum to close the gap between how science is done and how science is taught. Teachers and students have found that computational science enables them to understand a broad range of phenomena that are otherwise inaccessible. This includes phenomena that are too small (atoms and molecules), too large (galaxies and the universe), too fast (photosynthesis), too slow (geological processes), too complex (automobile engines), or too dangerous (toxic materials) to be studied in the undergraduate laboratory.

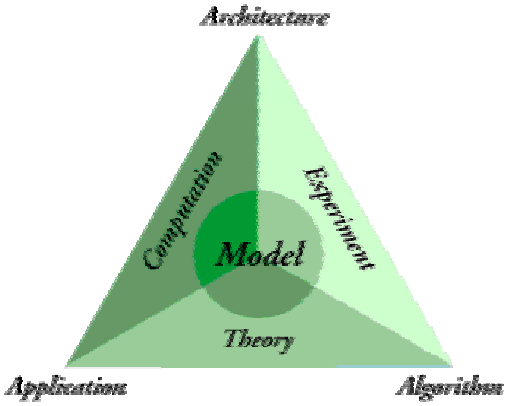


Figure 1.

Computational Science as Science Research

For centuries computation played a subservient role in science and engineering, helping experimentalists analyze their data or theoreticians assess their approximations. Science can no longer be divided only along the lines of experiment and theory. Computational science has arisen as *a new way of doing science*, enabling scientists to gain an understanding of our material world that cannot be obtained from experiment or theory alone. Since the development of digital computers fifty years ago, computational modeling has allowed scientists to better understand such complex processes as fluid flow and turbulence in physics, molecular structure and reactivity in chemistry, and structure-function relationships in biology. The relationship between experiment, theory and computation is illustrated in Figure 1.

Despite the increasing importance of numerical modeling in research and industry, computational science is not well represented in the undergraduate science curriculum. Today's science students, whose careers will extend to the middle of the 21*st* century, must understand the foundations of computational modeling, must be aware of the advantages and limitations of this approach to scientific inquiry, and must be able to use computational techniques to help solve scientific problems. Meeting these goals will require a bottom-to-top transformation in the undergraduate curriculum.

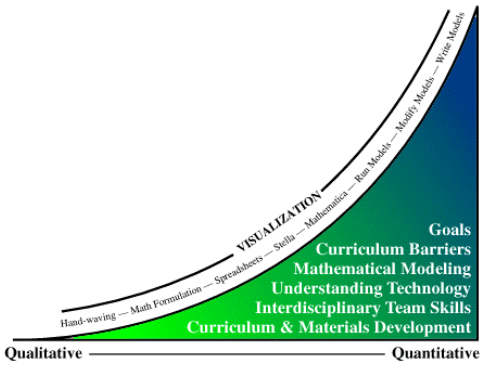
The Shodor Education Foundation, Inc.

The Shodor Education Foundation, Inc. is non-profit research and education organization dedicated to the advancement of science and mathematics education through the use of computational and communication technologies. Since its founding in North Carolina in 1994, Shodor has consistently pursued a focused vision for changing education at the undergraduate, secondary and middle school levels by allowing faculty and students to explore new learning and teaching modes based on interactive explorations enabled by the tools of mathematical modeling and visualization. In doing this, Shodor has established itself as a national leader in developing innovative modeling courseware in mathematics and many areas of science, including physics,

chemistry, astrophysics, biomedicine and environmental science. Shodor-developed materials have been repeatedly recognized as being the "best of the web" in education, including awards from the National Council of Teachers of Mathematics (NCTM), the Eisenhower National Clearinghouse (ENC), Encyclopædia Britannica, and Forbes.com.

The Path to Understanding

The founders of Shodor recognized that models lay at the heart of our understanding of the world around us and have used this knowledge to teach science as well as computational modeling. The "ramp" for learning about computational modeling is illustrated in Figure 2, which is a representation of Shodor's approach to teaching computational modeling. Our understanding of many physical, chemical and biological phenomena start with a qualitative "hand-waving" model, a model derived from simple theory and available experimental data that, nonetheless, provides important insights into the phenomena of interest. Formulating the theory as a rigorous mathematical model and then solving the resulting mathematical equations may refine this insight. More often than not, these equations can only be solved by using computers.



The next step along the path to understanding computational modeling is to use models developed by others to describe a problem of interest. These studies not only provide important insights into the phenomena but also may reveal deficiencies in the model being used to describe them. This leads the student to explore refinements of the model and, ultimately, to the creation of a new model, tuning the numerical solutions of the mathematical equations and the visualization and analysis of the output along the way. Just as Sisyphus ended up rolling back down as he tried to push a rock up a mountain, scientists often find themselves coming back to reformulate the mathematical model or even to rethink the hand-waving model, in order to properly describe the phenomena they are studying.

The National Computational Science Institute

With funding from the National Science Foundation and others, Shodor and a national team of collaborators have created the National Computational Science Institute (NCSI) to enhance the training of undergraduate faculty in computational modeling with workshops, tutorials, seminars, on-line resources, and network-accessible support. NCSI will ***pull*** teachers to attend regional workshops, ***push*** computational science at national meetings of scientific societies, and ***permeate*** the Web with courses and resources to teach computational science across the undergraduate curriculum.

Undergraduate faculty are of special importance since they teach future K-12 teachers as well as future graduate students and the future workforce. Simply put, undergraduate education is the *pressure point* for systemic educational reform and improvement. In addition, the gap between the nation's research universities and predominately undergraduate institutions is widening in many areas of science. This is detrimental to science and the nation. Across the country, most graduate students start in predominantly undergraduate institutions, and a growing number of students who graduate from four-year institutions start in two-year institutions. To reach these students, we must first reach their teachers.

Attracting Underrepresented Populations to Science

Shodor has demonstrated remarkable success in attracting significant numbers of women and minority students to their workshops, internships, and classes. The growing importance of achieving greater demographic diversity in the workplace in the U.S. was the focus of a recent study by Congress. This study underscored the imperative for expanding diversity in the workplace, especially in high technology areas, if the U.S. is to maintain a competitive edge in science, engineering, and technology.[1] Increased use of computational modeling to teach science may help the university system address this growing national need.

For more information on the Shodor Education Foundation, Inc., see http://www.shodor.org/.

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[1] Report of the Congressional Commission on the Advancement of Women and Minorities in Science, Engineering, and Technology Development, July 2000; see http://www.nsf.gov/od/cawmset.