Submitted for your consideration is a gallery of articles that chronicles only a few of the many successful efforts addressing the critical shortage of a diverse, well-prepared high-performance computing (HPC) workforce. Our goal, with this issue, is to stimulate large-scale international discourse to accelerate the adoption of the educational tools, curriculum, and pedagogy that reflect the increasing role of computational methods in science and engineering. Such approaches are necessary to educate a larger and more diverse population of well-skilled, knowledgeable, and innovative people who will significantly advance scientific discovery in all fields of study, now and well into the future.

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A New Challenge
During the past 30 years, all branches of the scientific community have increasingly relied on computational modeling as the third necessary and integral component of scientific discovery, with observation and experiment being the other two components. The world benefits from the enhanced quality of life directly attributable to these computer-based models and simulations in areas such as

- severe weather and climate prediction;
- healthcare and disease prevention;
- improved structural design for withstanding natural disasters;
- advanced aerodynamic and alternative fuels design;
- environmental management of natural resources;
- food production, product design, and safety;
- development of new materials;
- arts and entertainment; and
- new understandings of human history and social interactions.

The complexity of scientific discovery today requires HPC, which in turn drives the unprecedented growth of ever faster computing systems. In June 2007, the fastest supercomputer in the world clocked in at 280 teraflops (10^{12} floating-point operations per second); three months later, a single 80-core chip broke the teraflop barrier. By 2011, the research and education community will have access to sustained petaflop (10^{15} floating-point operations per second) computing systems, with today’s hardware designers already investigating exaflop (10^{18}) computing architectures.

An unexpected dilemma looms over this relentless drive toward abundant computer resources and transformative computational applications: the workforce to develop, implement, and conduct the analysis of these models is shrinking! Historically, the computational science emphasis has been on training graduate students and postdocs to apply HPC technologies to advance science and engineering research, with too few younger students involved in innovative computational science projects at a too slowly growing number of K–12 and undergraduate institutions. We now recognize the critical national and international need to advance computational thinking at all educational levels, to accelerate the integration of quantitative reasoning, modeling, visualization, and data analysis into the education of all students, as well as into professional development efforts for teachers, faculty, and researchers. Fewer students are entering the graduate phase of their careers with the foundation needed to succeed with advanced computational studies; the focus must shift to reach students at a much earlier phase of their learning.

Although we’ve seen many successes in meeting these challenges, as exemplified by the articles in this special edition, too many people in too many organizations still don’t understand why or how to implement these approaches in a systemic manner within educational institutions nationwide. It will take time and planning to revise the learning competencies for all students and to improve the professional development of teachers, faculty, and administrators. But most important, systemic change requires the resolve of administrators and educators to emphasize computational thinking and the associated learning goals that all students must achieve, at all levels of the educational system. If quantitative reasoning, computational thinking, and multiscale methodologies are part of everyone’s education, then we can develop the necessary and diverse skilled workforce required to address the national and global priorities for advancing science and engineering.

If you’ve had the opportunity to hear Bob Pannell, director of the US National Computational Science Institute, you’ll undoubtedly hear of “computational [long, loud breath] science education” that addresses the use of models and simulations to learn science, and “computational science [long, loud breath] education” that addresses learning how to create models and simulations to conduct science. It’s essential to advance the education of disciplinary specialists, mathematicians, and computer scientists because they each have critical roles in advancing computational science tools, resources, and methods to further scientific discovery; they all need to be well prepared to work as members of multidisciplinary teams. The educational process only benefits from these computational “science education” tools by training significantly more scientists via “computational science” education.

The unexpected truth is that our society has both the potential and the capacity to do an excellent job of preparing the next generation of computational thinkers—if we can agree to make this a necessary component in all fields and at all levels of formal and informal education. Every student has the capacity to gain the theory, practice, and experience to fully participate—if they’re provided with learning opportunities. We must ensure
that all students are provided with these opportunities to enable their full participation.

**In this Issue**

We transformed the “call for papers,” the genesis of this CiSE issue, into a call to action to integrate quantitative reasoning, modeling, and visualization for life-long learning in all fields. This is also a call to action to share successful strategies with as many people and organizations as possible. For example, the articles reference the use of the Computational Science Education Reference Desk (CSERD) to disseminate quality educational lesson plans, curricular materials, student activities, and related resources through the US National Science Digital Library. Given more space, we could have easily included many additional exemplars of similarly successful solutions.

In this issue, you’ll find six unique yet complementary approaches to advancing computational science that embody our call. We sincerely hope that you enjoy reading the successes exemplified in these articles and that you will help us find answers to the questions they raise, including:

- What will it take to transform science, technology, engineering, and mathematics education to prepare larger and more diverse generations of researchers, educators, and practitioners?
- How will we scale-up successful models among all of our nation’s schools, colleges, and universities?
- What are the obstacles and barriers, and how will we as a nation overcome them?
- How will we assess the impact of these programs for enhancing critical thinking skills and for preparing a knowledgeable workforce?
- What must we do to ensure that all people have the opportunity to fully participate both as learners and as members of the workforce?

We encourage you to join us in a national discourse addressing the learning and workforce challenges incumbent upon all of us to significantly advance scientific discovery. One place to further these discussions is the wiki at http://wiki.sc-education.org/CiSE. We look forward to hearing from you!

Scott Lathrop has dual appointments as the TeraGrid Director of Education, Outreach, and Training and as the Blue Waters Technical Program Manager for Education. He has been involved in high-performance computing and communications activities, working with researchers and educators for more than 20 years.

Lathrop coordinates education, outreach, and training activities among the 11 resource providers involved in the TeraGrid project and coordinates undergraduate and graduate education activities for the Blue Waters project. He coordinated the creation of the SC07-09 Education Program through the Supercomputing Conference to assist undergraduate faculty and high school teachers with integrating computational science resources, tools, and methods into the curriculum.

Thomas Murphy is a professor of computer science at Contra Costa College, chair of its computer science program, and director of its High-Performance Computing Center, which has supported both the Linux cluster administration program and the computational science education program. Murphy also works with the US National Computational Science Institute (NCSI) and is one of four members of the NCSI Parallel and Distributed Working group, which presents several workshops each year. His current interests include exploration of the metaverse for teaching and training, developing camerless classroom video podcasts, inexpensive electronic white boards, and carryon attaché clusters. Contact him at tmurphy@contracosta.edu.

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**A Survey of Computational Physics**

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