A Shared, Interinstitutional Undergraduate Minor Program in Computational Science

Nine Ohio higher education institutions collaborated to develop an interinstitutional curriculum in computational science, combining expertise and resources across campuses. Key program features include interdisciplinary competency requirements, sharable instructional modules, and interinstitutional agreements for cross registration.

Recognition of the economic importance of high-performance computing and advanced computational science is growing. A Council on Competitiveness survey of chief information and chief technology officers indicated that 97 percent of major companies couldn't function without high-performance computing and computational science.[1] These companies use large-scale modeling and simulation to discover new processes, design products, manage markets, and get products to market faster and cheaper. This technology is critical to their continuing competitiveness in the global market. Moreover, a US National Science Foundation Blue Ribbon Panel on Simulation-Based Engineering Science recommended expanding development of interdisciplinary programs in computational science.[2] As the study and the "Guest Editors' Introduction" to this issue (see p. 9) point out, modeling and simulation are the keys to future US leadership and innovation in science and engineering.[3]

Computational science is an interdisciplinary field encompassing three major elements:

- modeling and simulation software to solve science, engineering, and humanities problems;
- computer and information science to develop and optimize the advanced system hardware, software, networking, and data management components needed to solve computationally demanding problems; and
- computing and networking infrastructure to support science and engineering problem-solving.

To address their research problems, computational scientists need a combination of domain-level science and engineering expertise, familiarity with the required computer and information science tools, and infrastructure access.

The US Department of Labor doesn't make exact forecasts for jobs requiring computational science skills. However, as a path to discovery, we extracted relevant occupation data based on the fields that we know incorporate computational science. Figure 1 shows forecasts through 2016.

1521-9615/08/$25.00 © 2008 IEEE
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Scaling programs to address the emerging workforce demands remains a challenge. To meet it, a consortium of nine Ohio higher education institutions, the Ohio Supercomputer Center, and the Ohio Learning Network (OLN) designed a shared undergraduate minor program in computational science. This program combines expertise across institutions, reducing the total number of courses taught on each campus and extending participating campuses' capabilities. The program also creates a larger pool of students, facilitates the exchange of course materials (such as model examples, data sets, and student assignments), and helps develop communities of practice.

In developing the program, we identified several major issues that required collaborative resolutions:

- Faculty must agree on a common curriculum and a mechanism for assuring that students meet curriculum objectives regardless of which institution carries out the instruction.
- Institutions must approve the curriculum and agree to registration issues such as dual registration and transfer credit.
- Institutions must agree to equitably share in the program's costs and associated revenues.

How we resolved these issues in Ohio can serve as a model for other institutions to build interdisciplinary, interinstitutional education programs.

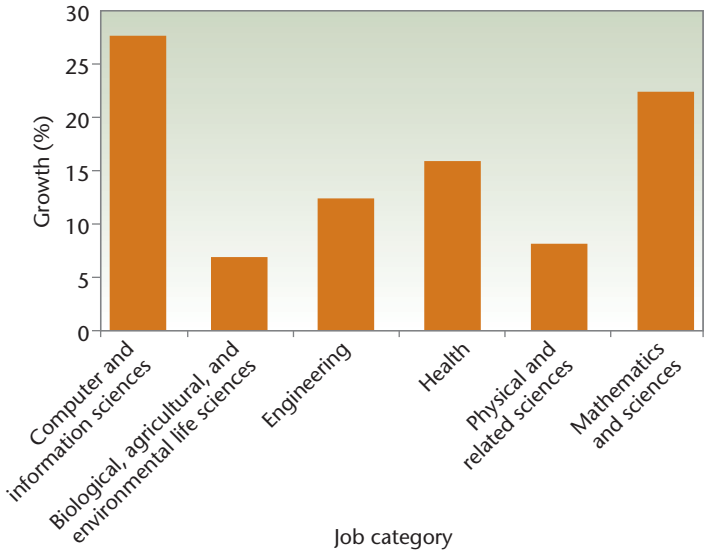

Figure 1. Growth in science and engineering jobs, bachelor's degree only, 2006–2016. (Source: US Department of Labor, Bureau of Labor Statistics; used with permission.)

The State of Computational Science Education

Assembling the resources to create sustainable programs in computational science is difficult. Expertise is generally distributed across traditional departments and colleges, with few faculty experts in any one program. The primary work assignments for those faculty rest in courses in their home department programs. Faculty can add computational science components to those courses, but they typically can't assemble a curriculum that provides students with interdisciplinary expertise in computational science. Similarly, faculty in computer and information science focus on their disciplinary programs. Although some programs have faculty with expertise in high-performance computing, the core of most programs focuses on the field's traditional facets, such as software development and algorithms, database management, and computer-human interactions.

Access to the appropriate infrastructure for educational uses also can be problematic. If faculty obtain the appropriate resource allocations, they can access US National Science Foundation and US Department of Energy Centers. However, the allocation policies and the learning curve for effectively using one of these centers can be inhibiting. Also, computer simulations might sit in queues for hours or days, making it difficult for faculty to demonstrate the software's use to a class or to time a class assignment. Although institutional or departmental computing clusters are becoming more common and available for classroom use, there are still limitations related to cluster size, software availability, software license costs, and hardware maintenance expenses. Many departmental clusters run only a handful of disciplinary-oriented codes and might not be available for other departments' use.

Several computational science programs have overcome some or all of these barriers to create either disciplinary-focused or comprehensive computational science programs at the undergraduate level. For instance, State University of New York at Brockport (http://cps.brockport.edu) offers an undergraduate major in computational science. A few institutions have developed computational science curricula offered as undergraduate minor programs. Examples include Capital University (www.capital.edu/68/Arts-and-Sciences/Computational-Studies), the University of Wisconsin Eau Claire (www.cpsc.uwec.edu), Clarkson University (www.clarkson.edu/mcs/math/undergrad/minors.html#computational), and Wof-

ford College (www.wofford.edu/ecs). Other undergraduate curricula include major or minor programs in computational science studies in biology, chemistry, economics, engineering, finance, physics, and so on. For example, Oregon State University offers a BS in computational physics (www.physics.oregonstate.edu/~rubin/CPUG/). Additionally, Shawn Sendlinger and colleagues in their article on p. 34 describe a special program for high school chemistry faculty. A 2006 Society of Industrial and Applied Mathematics report features a more comprehensive review of recent undergraduate computational science and engineering programs.[4]

Our program, however, is more comprehensive, involving a broader range of science and engineering disciplines, a common core curriculum, and a set of collaborative arrangements that enables our institutions to share faculty expertise, experience, and resources.

Defining the Program Structure

The Ohio efforts began with posting a white paper outlining the concept of a shared, statewide program in computational science and inviting online comments of faculty from around the state. We also referred participants to the reports we've cited and other supporting materials, such as Osman Yaşar and Rubin Landau's work.[5] Next, interested faculty from community colleges, four-year public universities, and four-year liberal arts colleges representing biology, chemistry, computer science, engineering, environmental science, mathematics, and physics worked both face to face and remotely to define a common skill set undergraduate students would need to understand the application of computational science to their discipline. Online discussion focused on the required skills in mathematics, modeling and simulation, and computational science's disciplinary applications.

After several discussions, we reached consensus on program requirements, including the following major topic area requirements:

- simulation and modeling,
- programming and algorithms,
- differential equations and discrete dynamical systems,
- numerical methods,
- optimization,
- parallel programming,
- scientific visualization,
- one discipline-specific course, and
- capstone research or an internship.

However, for each topic, it was unclear what set of skills students would derive from understanding and applying the topic. For example, everyone agreed that numerical methods are essential but not necessarily all of the information contained in a traditional mathematics course on numerical methods.

To address this problem, participants in various subcommittees used online collaboration tools to draft and discuss the overview courses' specific competencies. We left the contents of the discipline-specific course and capstone course for a later discussion. Each subcommittee proposed a set of competencies, which the full group discussed and approved. This process built a common understanding of the minimum requirements associated with each topic.

Competencies in hand, we sought the advice of a business advisory committee. That group reviewed and commented on the competencies through an online survey, then met to discuss the competencies. They corroborated about 80 percent of the competencies and suggested improvements. For example, they encouraged a deeper concentration on visualization throughout the curriculum and added examples of Monte Carlo and other probabilistic simulation techniques.

The final set of competencies became the basis for the curriculum available on the program Web site at www.rrscs.org/minor/minor.shtml. Each course in the curriculum must meet a subset of the competencies.

Creating Shared Course Materials

The competencies guided the preparation of instructional modules. Each module contains a description of prerequisites; software requirements; a description of the problem statement, background, model, and method; and one or more student assignments, including an assessment rubric and empirical data, if relevant. Each module also identifies which of the competencies it meets.

Modules are complete for most of the core competencies, and the remaining modules will be done by Autumn 2008. The completed modules include topics from biology, chemistry, computer science, engineering, mathematics, and physics.

The modules are incorporated into the shared program's courses. All course materials will be in a shared repository, providing access for all, minimizing faculty preparation time, and ensuring instruction continuity. Many of the modules will also be shared nationally through the Computational Science Education Reference Desk digital library (see "Education, Outreach, and

Training for High-Performance Computing" on p. 40). Steven Gordon has participated in that project, helping establish the review process for submitted materials.

A faculty committee will meet biannually to consider changes in the curriculum and approve new courses and course materials. This lets the curriculum evolve as the field, software, and hardware evolve.

Interinstitutional Agreements

A shared curriculum requires full support of an institution's academic infrastructure. Policy documents and consortia agreements exemplify this support. Numerous models exist, including the Great Plains Interactive Distance Education Alliance (www.gpidea.org), the League of Innovation's Project SAIL (www.league.org/league/projects/sail/index.htm), and, in Ohio, the Northeast Ohio Universities College of Medicine (www.neoucom.edu) and the Southwest Ohio Consortium of Higher Education (www.soche.org).

Creating consortium agreements to address the administrative and financial issues associated with this program was a year-long endeavor. Issues we resolved included developing registration and grade transfer processes, scheduling classes, and sharing the courses' associated revenues.

A committee representing distance learning units, academic affairs, registrars, and deans from universities, independent liberal colleges, and community colleges worked through issues to create the consortia agreement. The OLN and the Ralph Regula School of Computational Science cofaciliated the discussions, each focusing on its strengths: policies and procedures for OLN, and competencies and curriculum for the Regula School. Provosts at the nine participating institutions signed the consortia agreement.

A common vocabulary was central to the discussions and the consortia agreement. A clear understanding of the "home" institution versus the "host" institution was key to determining other policies and procedures. We defined the following terms:

- *Home institution*: The institution where the student is admitted as a student. Home students "visit" other institutions through Regula School courses.
- *Host institution*: The institution that employs the primary course instructor. Host universities "teach" the Regula course.
- *Participating institutions*: Colleges and universities that have elected to participate in sharing courses through the Regula School.
- *Faculty coordinators*: The staff in the participating institution responsible for helping students register for courses; shepherding courses for approval by the dean, department heads, and curriculum committees; arranging technical support, as needed; and communicating with their home registrar and the Regula School.
- *Registrar contacts*: The staff in the Registrar's Office of the participating institutions who are responsible for sending and receiving Regula-related information to the faculty coordinators, the host or home registrars contacts, and the Regula School.
- *Technical contacts*: The staff at participating institutions responsible for providing related technical support, such as video conferencing and student support services.
- *Visiting students*: Students from institutions other than the host institution who participate in Regula School courses.

Following home institution policies made it easier to create consortium registration polices. The registrars agreed to pass information to the hosting institution and transfer grades after course completion. This solution works as enrollments remain small. As the enrollments grow, we will implement data-driven Web processes in collaboration with a larger statewide project.

Institutional business officers and academic officers agreed on the tuition policies. Tuition ranged from US$45 per credit hour in the community colleges to $350 per credit hour in the state universities to more than $1,000 per credit hour at the independent colleges. The Regula School modeled scenarios that illustrated no single institution would lose money unless more credits hours were exported than imported. These scenarios demonstrated that the financial risks were small and the potential benefits to students and faculty were substantial. Thus, it was possible to agree on a standard fee of $250 per credit hour. The full agreement is available on the school Web site at www.rrscs.org/minor/RRSCSagreement.pdf.

At this early stage, it might be premature to define all of the elements that have made this program an initial success. Several major factors, however, appear to have facilitated the program's development. Although the institutions have faculty interested in participating in the program, the impetus for starting and maintaining the program origi-

nates from two statewide organizations: the Regula School and the OLN, both Ohio Board of Regents initiatives. Those organizations have a broader mission to facilitate interuniversity programs as well as a neutral reputation with respect to interinstitutional rivalries.

A second major factor in the program's early success is that no single institution was prepared to teach all of the courses the curriculum required. All institutions receive the benefit of offering a new curriculum without having to organize the entire effort and at a nominal cost.

Finally, the shared curriculum gives participating faculty the chance to join a larger community of practice. These faculty are often in the minority in their departments and universities.

As the program moves forward, we'll conduct periodic assessments from an educational and organizational perspective and adjust the program to reflect that experience. Current improvement efforts include publicizing the program and rounding out and seeking additional participation from other interested institutions statewide.

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