

### ***The NSF Cyberinfrastructure Vision for 21<sup>st</sup> Century Discovery***

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In July, 2007, the National Science Foundation hosted a two-day workshop in Washington D.C. concerning its ***Cyberinfrastructure Vision for 21<sup>st</sup> Century Discovery***. This recently released document (March 2007, <http://www.nsf.gov>), developed in consultation with the wider science, engineering, and education communities, describes an evolving vision to guide future investments by the NSF in cyberinfrastructure (CI) over the next five years. The CI vision is a bold one that encourages the use of cyberinfrastructure-mediated tools to collaborate and communicate in ubiquitous learning environments and virtual organizations. It urges the development of new kinds of learning and research cultures that support peer-to-peer modes of education and enable distributed knowledge communities transcending traditional disciplinary, institutional, geopolitical and cultural boundaries. Realizing this vision will require leveraging resources through multiple and diverse partnerships among academia, industry and government, with the anticipated rewards being strengthened innovation, economic growth and education.

Several objectives of the NSF CI vision are pertinent to the California State University and its mission:

- To change the organizational enterprise of learning
- To foster deployment and utilization of cyber-enabled learning and research environments
- To study the evolution and impact of cyberinfrastructure on the culture and conduct of research and education

While it is beyond the scope of this article to discuss the workshop and vision document in their entirety, I will focus on two overlapping and complementary aspects of the discussion: Cyber Services and Virtual Organizations, and Learning and Workforce Development. Next, I will provide selected relevant examples of activities utilizing CI at Cal State Fullerton's W.M. Keck Foundation Center for Molecular Structure and the Department of Chemistry and Biochemistry. Finally, I will highlight some key results from a recent study of "Undergraduate Students and Information Technology" conducted by the Educause Center for Applied Research.

#### ***Cyber Services and Virtual Organizations***

Cyberinfrastructure is defined as *the coordinated aggregate of software, hardware and other technologies, as well as human expertise, required to support current and future discoveries* (NSF Office of Cyberinfrastructure, OCI). This includes:

- Data analysis and management
- Computationally intensive tasks and process management
- Data mining and integration
- Automation (sample and data management)
- Visualization and modeling
- Remote collaboration tools (interactive conferencing; remote sensing; remote access/control of instrumentation)

Virtual Organizations (VOs), also defined as collaboratories, grid-communities/networks, virtual communities and e-communities, are groups of individuals whose members and resources are dispersed geographically and/or temporally, yet who function as a coherent unit through the use of end-to-end cyberinfrastructure. Virtual organizations are revolutionizing the conduct of research and education. Examples of VOs with which you may already be familiar include:

- Network for Earthquake Engineering Simulation (NEES)
- National Virtual Observatory (NVO)
- National Science Digital Library (NSDL)
- Grid Physics Network (GriPhysN)
- Biomedical Informatics Research Network (BIRN)
- DOE National Collaboratories Program
- DOE Scientific Discovery Through Advanced Computing
- Corporation for Education Network Initiatives in California (CENIC)

The last VO in this list, CENIC, designs, implements, and operates CalREN, the California Research and Education Network, a high-bandwidth, high-capacity Internet network specially designed to meet the unique requirements of faculty, staff and students in these communities, and to which the vast majority of the state's K-20 educational institutions are connected.

Software essential to the creation of networked resources and virtual organizations encompass a broad range of functionalities and services, such as enabling middleware; domain-specific software and application codes; teleobservation and teleoperation tools to enable remote access to experimental facilities, instruments and sensors; collaborative tools for experimental planning, execution and post-analysis; workflow tools and processes; system monitoring and management; user support; web portals to simulation software and domain-specific community code repositories; flexible user interfaces to enable learning and discovery. Many of these types of cyber services are fundamental to the CSU Digital Marketplace Initiative (DMI) and required for its infrastructure. Cyber security pervades all aspects of end-to-end cyber-based systems and VOs, including software, data, facilities and human elements. The NSF expects VOs to develop and deploy robust cyber security policies and procedures, with the objective of promoting a conscientious and consistent approach to cyber security.

### ***Learning and Workforce Development***

Cyberinfrastructure is enabling powerful opportunities to collaborate, model and visualize complex concepts, create and discover scientific and educational resources, assess learning and personalize learning. New methods to observe, acquire, manipulate, transform and represent data challenge our traditional discipline-based curricula. The necessary knowledge and skills (learning and workforce development) needed to design, deploy, adopt and apply cyber-based systems are changing how we teach and how we learn to prepare a ***globally engaged*** workforce. These changes demand and support a new level of technical competence, termed “technical fluency”, in the science, engineering and education workforce, as well as citizenry at large. The NSF believes that cyber tools must be incorporated within the context of interdisciplinary research and education.

Cyberlearning, defined as the interaction of education, cyberinfrastructure and learning sciences, is considered one of the grand challenge problems by the NSF. The NSF seeks to build a better understanding of how individuals, teams and communities most effectively interact with cyberinfrastructure. The vision of the NSF is one where formal and informal learning are blended, transcending conventional boundaries and school-based education. Portable and personal technologies (mobiles and laptops) will be utilized to create virtual environments and centers, as well as immersive worlds. Informal learning environments will be engaged in lifelong and lifewide learning. Cyberinfrastructure can capture learners' profile, background and interaction data, enabling scientific understanding of learners. Communities of learners can be facilitated through virtual environments, where social networking functions and aggregate communities of interest evolve to learning and practice, which can then be harnessed for education. Teaching can be improved and enhanced through cyberinfrastructure.

Because cyberinfrastructure is dramatically altering the conduct of research and education, the NSF also supports studies of the evolution and impact of cyberinfrastructure on the culture and conduct of research and education within and across communities of practice. Education policy with regard to

cyberinfrastructure must be addressed with regard to privacy, security, utilization, equity of access, and ownership elements. The NSF would like to know how best to design critical governance and management structures for these new types of organizations, as well as how to improve allocation of resources and initiatives. Because CI rapidly evolves, comprehensive user assessments are necessary to identify and evaluate how CI affects our ability to conduct transformative research and provide rich learning and workforce development environments. Other issues to be addressed include how and to what degree CI facilitates inquiry, interoperability and the development of common standards and new social norms.

The grand challenge problem of cyberlearning is an attractive vehicle for funding, and it will have significant impact when solved. Solving this grand challenge problem requires overcoming fundamental barriers to creation and utilization of cyberlearning tools, resources and services. These include:

- 1) **developmentally relevant learning support:** distributed learning system in real time to discover resources, peers and mentors with verifiable reputations to help attain competencies
- 2) **tacit interest analysis:** interest profile to engage content and scenarios for pursuit of enhanced skills and competencies; ensure appropriate privacy safeguards; these systems exist (iTunes, Amazon, etc)
- 3) **systems for learning performance certification and reputation management on a global scale:** distributed expertise making possible goal directed learning; foster "learning cooperatives"; broker needs and services via cyberinfrastructure
- 4) **lifelong digital learning portfolios:** for cyberinfrastructure management media developed by a learner over lifetime, and indexed for one's reflective learning and certification process
- 5) **informed digital earth:** provision of cyberinfrastructure systems, tools and services to enable location specific read write sensing, tagging and interactive visual analytics for ubiquitous learning about natural and cultural environments (Google earth on steroids)
- 6) **language to language translating capabilities:** facilitate exchanges and access across learning resources
- 7) **reflexive cyberinfrastructure systems:** report on our own behavior, diagnosing whether we are meeting performance criteria
- 8) **simulating learning with cyberinfrastructure systems:** develop more effective learning support conditions; examine different designs to achieve learning outcomes; use new knowledge to address other grand challenge problems

### **W.M. Keck Foundation Center for Molecular Structure (CMoIS)**

Practically all information about the molecular structure of matter at atomic resolution is the result of diffraction analysis, using data obtained by X-ray, neutron and electron diffraction methods. Diffraction methods have contributed to our fundamental understanding of chemical bonds, chemical reactions and biochemical pathways, the composition and properties of minerals and ceramics, and to the design of materials, pharmaceuticals, crystals, and enzymes. The Center for Molecular Structure (<http://chemsrvr2.fullerton.edu/CMOLS/index.htm>) at Cal State Fullerton is the third of several core facilities for the California State University Program for Education and Research in Biotechnology (CSUPERB).

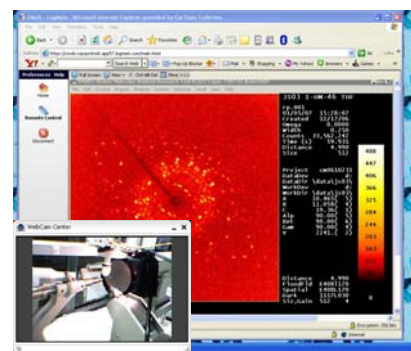
Conceived in 1992 and established in 1994, CMoIS was the first facility of its kind at a Predominantly Undergraduate Institution (PUI), dedicated to molecular structure determination and analysis using X-ray diffraction and computational methods. The high performance computational facilities went online to the



**Internet connectivity map of the STaRBURSTT CyberDiffraction Consortium. Red stars denote core node facilities.**

CSU in 1995, and instruments became available for research and training in 1996. *The X-ray diffractometers were made remotely accessible to students and faculty in the CSU in the summer of 1997, six months before the DOE National Collaboratories became accessible to remote users.* In 2005, CMoIS joined with four other PUI laboratories and became the west coast core node of the nationwide STaRBURSTT<sup>a</sup> CyberDiffraction Consortium (<http://www.starburstt.org>). Through the use of cyber-enabled instruments for research and education, the STaRBURSTT-CDC aims to systematically and significantly change the research and educational cultures at PUIs. This consortium currently engages 150 PUIs, including Community Colleges, Historically Black Colleges and Universities, Hispanic Serving Institutions, and Tribal Colleges. We also collaborate closely with a range of affiliate members such as Ph.D. granting Universities, Government Labs, Non-Profit Organizations, and Companies. Additional scientific instrumentation cyber-enabled in the broader STaRBURSTT cyberinstrumentation consortium include nuclear magnetic resonance and mass spectrometers.

In addition to providing secure remote instrumentation access for research and education, CMoIS regularly hosts web-based seminars (webinars) and NSF-sponsored professional development workshops for faculty and secondary teachers to disseminate methods and pedagogy utilizing cyberinfrastructure. We have also begun teaching courses in X-ray diffraction and molecular structure analysis *across campuses* using the same web conferencing tools to actively engage student learning communities as utilized for remote access to our instruments (iLinc Communications™). Interactive sessions, lectures, and laboratory demonstrations are routinely recorded and made available to students as pod casts. I have also taught several sessions of courses in biochemistry and scientific writing utilizing these same web conferencing tools. The latter course makes extensive use of productivity tools, including citation managers, presentation software, and peer-reviewing and markup tools, as well as primary literature and scientific databases. Students engaged in all the above activities are given both formal and informal assessments, including online pre- and post-course surveys about the use of and preferences for cyberinfrastructure. To further leverage NSF funds, CMoIS has partnered with the NSF-sponsored Common Instrumentation Middleware Architecture (CIMA) project at Indiana University (<http://www.iumsc.indiana.edu/>), whose objective is cyber-enabling instruments as real-time data sources to improve accessibility of instruments. As a CIMA early participant, CMoIS deposits its X-ray diffraction data into a long-term archive at IU at no cost, and data archived at CIMA by each collaborating laboratory are available to the other laboratories for instructional purposes.



**Captured computer screen of remote access session. Shown is the data acquisition software application and status of the sample in the X-ray beam from a webcam.**

### ***ECAR Study of Undergraduates and Information Technology***

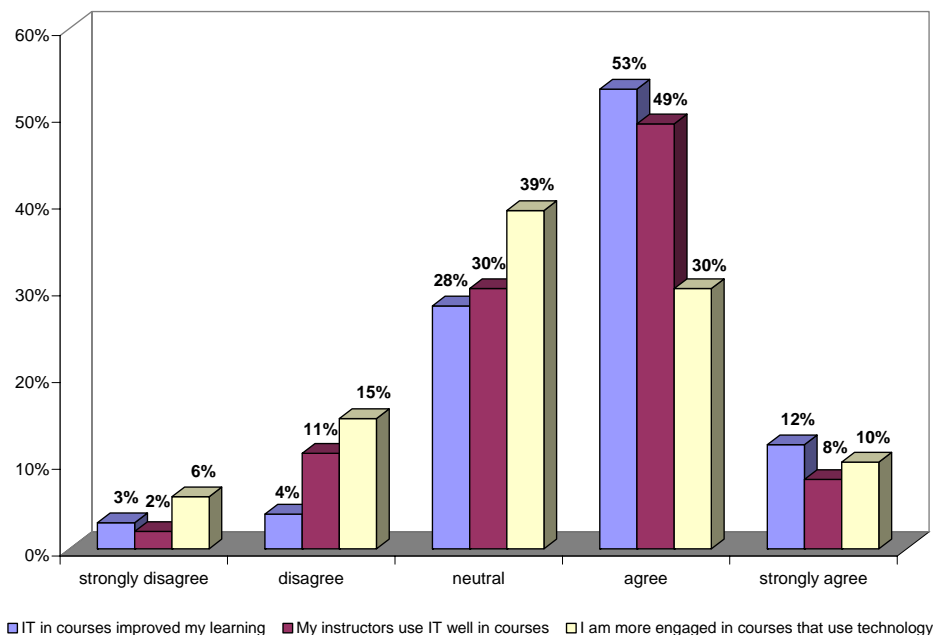
Today's students are usually regarded as being techno-savvy, with more advanced technology skills and usage experience than previous student populations. It is also generally acknowledged that there is a digital divide among students, a gap between those with regular, effective access to digital and information technology, and those without this access. In this context, access means both physical access to technology hardware and, more broadly, skills and resources which allow for its use. This digital divide may fall along socioeconomic, racial or geographical boundaries. Furthermore, the digital divide may extend to an educational divide, when technology skills and usage experience and/or pedagogical views influence the use of technology in courses, as well as in scholarly and creative activity.

To validate, deepen, modify or refute the many characterizations of undergraduate students, in 2006 the Educause Center for Applied Research examined students' use of and skills with information technology, and their experiences with IT in their courses. Students at 96 higher education institutions

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<sup>a</sup> Science Teaching and Research Bring Undergraduate Research Strengths Through Technology

were studied, and ECAR believes that the statistically significant results are indicative of student behavior at many similar institutions. Selected results from the ECAR study are highlighted below.



**Student evaluation of IT in courses.<sup>b</sup> Student survey responses to questions on quality of learning, use of technology by instructors, and engagement in courses utilizing IT.**

The key findings of the ECAR Study of Undergraduate Students and Information Technology 2006 indicate that:<sup>b</sup>

- Nearly 98% of undergraduate respondents own a personal computer.
- Nearly 67% of undergraduates own laptops.
- More than 75% of freshman from four-year institutions own laptops.
- Students' use of technology is strongly influenced by academic major and class status.
- Students say convenience is the primary benefit of IT in their courses.
- Most students prefer a moderate amount of IT in their courses.
- More than 64% of respondents agree or strongly agree that IT has improved their learning.
- Almost 75% of respondents have used a course management system. Most report a positive experience.
- The more students use a course management system, the more they prefer its use.
- More than 40% of students indicate that they are more engaged in courses that use technology.

Based on these findings, ECAR recommends that certain observations deserve further consideration. First, undergraduates are a diverse group. While younger students are perceived overall as ready technology adopters and eager for IT in their courses, they identify themselves as less skilled with specialized software than older students, while older students are likely to want additional training. Second, curriculum matters when it comes to development of needed IT skills for students. Students tend to learn technologies because they are required in courses. Engineering and business students report the highest use and skill with presentation and spreadsheet software, while fine arts students report greater

<sup>b</sup> Adapted from Caruso, J. B. (2007) Students Reveal IT... Likes and Dislikes, Academic Sourcebook, Supplement to Advantage Business Media, p. 28.

skill with graphics software. This diversity of “technical fluency” may have a significant impact on quality of learning and workforce development within the context of interdisciplinary research and education. Third, the use of technology changes as undergraduates mature, and institutions should address to what extent more specialized technologies can be introduced earlier in students’ academic careers. Fourth, IT in courses continues to be largely about convenience. If technologies are adopted, they should be robust. Finally, across academic major and class status, overall, students prefer a moderate amount of technology in courses. Bear in mind, there are those students who want technology to be a supplement to the classroom experience and not a replacement, while there are also those students who find completely online courses highly valuable, as these enable them to access a course at their convenience.

### **Closing Remarks**

The NSF CI vision mandates cyber-enabled life-long learning, to create and use CI in research and education, broaden participation, and explore integrated research and education, beginning in K -12 education and extending well into adulthood. Integration of research and education is expected to facilitate acquisition of knowledge and skills needs to develop, deploy, adopt and apply cyber-based systems and prepare a **globally engaged** workforce. By leveraging teaching expertise and instructional practices to improve academic effectiveness and efficiencies, the DMI provides some types of *cyberinfrastructure-mediated services* in step with federally mandated cyberinfrastructure initiatives.

We are at an inflection point where increasingly research and education are taking place in CI environments and VOs. Transformative learning, education, discovery and research can increase the quality, quantity and impact of learning through CI. The CSU is ideally poised by mission, expertise, partnerships, and an existing foundation of infrastructure to begin to address the grand challenge problem of cyberlearning. Cyberinfrastructure, by facilitating learning and workforce development, is as critical to our teaching mission as to our research mission. In accord with the NSF CI vision, the CSU should strive to support high gain scholarship and creative activity in developing sophisticated applications for achieving the goals of research and education communities. The associated challenges to foster deployment and utilization of cyber-enabled learning and research environments can be overcome with committed investment of time and resources, complemented by a cultural transformation in the conduct of research and education that is sustained by *both* faculty and curriculum development.