University Futures and New Technologies: Possibilities and Issues

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1 Background

This is an invited paper intended to be a starting point for brainstorming, discussion, and scenario building at an invitational workshop of experts to explore the push and pull of new technologies -- largely information and communication technology (ICT) -- on learning, teaching and research in higher education. The OECD Centre for Educational Research and Innovation (CERI) convened this workshop as part of a project on university futures. The project is international in focus and includes the entire post-secondary sector, not only the research university. Technology is one strand of reflection that will also include consideration of demography, massification, the labor market, internationalization, globalization[1], intellectual property rights, and status of the academic profession. Besides the changes that technology can induce in learning, teaching and research in the future, it will likely the impact the design of physical and virtual university environments, as well as its relationships with intellectual property rights.

In this paper we briefly review some of the growing literature on the topic of ICT and the future of higher education; propose a framework for envisioning some of the possibilities (largely based on initiatives in the sciences as harbingers of broader impact); and conclude with strategic issues and questions for further deliberation. The paper is a work in progress intended to be embellished and extended based upon dialog among experts from diverse international perspectives.

There is going awareness and deliberations on the future of higher education, particularly in the context of the information technology revolution and the associated emergence of globally competitive, knowledge-based economies. There is a contemporary literature building on this topic including a series of reports from studies sponsored by the U.S. National Academies of Science, Engineering, and Medicine [1-3], a website from a visioning process sponsored by the Carnegie Foundation [4], the OECD Centre for Educational Research and Innovation (CERI) [5, 6], and a set of provocative books, for example [7-10]. A recent collection of papers by American and European academic leaders under the title *Reinventing the Research University*, edited by Weber and Duderstadt [10] is particularly relevant to this workshop because of its international orientation. In the U.S., veteran university leaders Frank Rhodes [11] and more recently

[1] Including reports in the New York Times (21 Dec 2004 by Sam Dillon) that the U.S. slipping in status as the world hub of higher education.

Charles Vest [12] offer broad treatments of the future of the university with some material relevant to the role of ICT.

While not primarily focused on the future of the university in the context of ICT, Pelikan [13] is a refresher on the origins and fundamental mission of the university. Reading it provokes the question of whether the traditions of unity from diversity (uni-versity) or universality of scholarly communities can be maintained in an explosive knowledge world without adopting new forms and methods based on information technology. What does it mean to call yourself a “university” in a highly connected world enabled by information technology? Susanne Lohmann’s (lohmann@ucla.edu) pending book, *How Universities Think*, [14] will be a must read for higher education futurists. It provides a contemporary, systemic treatment of this complex institution, and most relevant to this paper, it creates substantial doubt that Peter Drucker’s famous prediction that “thirty years from now the big university campuses will be relics” will come true. More importantly, it also makes vivid that while the following quote by Clark Kerr with respect to universities *is* true:

about 85 institutions in the Western World established by 1520 still exist in recognizable forms, with similar functions and with unbroken histories, including the Catholic Church, the Parliaments of the Isle of Man, of Iceland, and of Great Britain, several Swiss cantons, and 70 universities;

that the longevity of the university is *not* a result of never changing – but rather a credit to its ability to evolve, adapt, and change over time. The continuing power and ubiquity of information and communication technology is now creating another need and opportunity to do so.

Our approach is to develop frameworks, point of views and terminology for this conversation; to suggest a set of generic possibilities that could be building blocks for scenarios; and to illustrate some of these possibilities through examples of initiatives underway. We are striving for a treatment that is abstract and generic enough to apply to a broad notion of higher education – not just the research university – but grounded enough to evoke specific scenarios and courses of action. This version of the paper is not balanced with respect to international initiatives – it will be biased towards the work best known to the author in the U.S. But a goal of the paper is to help remedy this deficiency by encouraging international institutional cooperation on visioning, strategy development, and creating ecologies of experimentation to better understand how to apply technology to more broadly and deeply realize the fundamental mission of higher education.

2 Frameworks, Points of View, Terminology

2.1 ICT as a cross-cutting force

The knowledge economy is demanding new types of learners and creators. Globalization requires thoughtful, interdependent and globally identified citizens. New technologies are changing modes of learning, collaboration and expression. And widespread social and political unrest compels educational institutions to think more concertedly about their role in promoting individual and civic development. Institutional and pedagogical innovations are needed to confront these dynamics and insure that the canonical activities of universities -- research, teaching and engagement -- remain rich, relevant and accessible.

ICT is one force for change together with others including demography, massification, the labor market, shifting public attitudes, internationalization, intellectual property rights, the state of the academic profession. ICT continues exponential grow in the capacity of computation, storage, and communication technology combined with the (much slower) progress in socio-technical understanding about how to apply these technologies to knowledge-based activities. ICT is often treated independently as one force co-linear with the others. This point of view limits the space of new possibilities because it fails to appreciate that ICT is actually cross-cutting with respect to the other forces and can be the basis for new organizational forms and ways of learning, discovery and creation that affect all the others.

New technologies afford a suite of opportunities to meet the challenge of the knowledge economy. ICT enables new communication structures that radically reduce constraints of distance and time, and enable novel environments for research, teaching and engagement. These new environments can augment what universities have historically done well by offering new possibilities for creating learning communities to build, explore and apply knowledge in pioneering ways to meet changing societal needs and realities. As noted by John Seely Brown, "It's probably less helpful to say simply that the university will change because of changing technologies than to say the emerging computational infrastructure will be crucially important in retooling the already changing university and in providing access to these students of tomorrow." [15] Universities are changing in part because of changes in societal needs, including increasing populations of traditional and non-traditional students, need for new styles of pedagogy, and economies that make educated people and ideas more important." Brown's comment also suggests that we not view the future of higher education as purely a product of technological determinism.

ICT can enable "and-and" organizations as opposed to "either-or." An ICT enabled organization can in effect can be both big and small, local and global, centralized and decentralized. A response to massification need not depend solely on more bricks and mortar and traditional classrooms instruction. ICT-based solutions, e-learning, are possible but should be comprehensive enough to avoid creating second class, off-campus students without full access to the library, laboratories, and informal serendipity learning opportunities with instructors and peers.

2.2 Higher education institutions as knowledge communities

The author's point of view on the nature of "universities in the digital age" has been strongly influenced by the essay of the same name by John Seely Brown and Paul Duguid [15]. They assert that the value of a university lies in the complex relationship it creates between knowledge, communities, and credentials. They suggest, "it is a mistake to think of the university "delivering" knowledge or students as "receiving" it. Central to higher education is the way universities provide access to *communities of scholars and testimony for a student's experience among these communities.* Consequently, universities should explore resources (most especially ICT) for bringing people together, not, as some interpretations of "distance education" suggest, for reinforcing their isolation." Brown and Duguid assert "communities are at the heart of what universities do…"

A community view, they suggest,

> *allows a more rounded view of what learning, all learning, is and how it happens. A delivery view assumes that knowledge is made up of discrete, pre-formed units which learners ingest in smaller or greater amounts and in specialized settings until graduation or indigestion takes over. To become a physicist, such a view suggests, you need to take in a lot of formulas and absorb a lot of experimental data. But, on the one hand, knowledge is not a static, pre-formed substance; it's constantly changing and learning involves active engagement in the processes of change. And, on the other, people don't become physicists by learning formulas any more than they become football players by learning plays. In learning how to be a physicist or a football player-how to act as one, talk as one, be recognized as one-it's not the explicit statements, but the implicit practices that count.*
>
> *The central point is that learning does not occur independent of communities and consequently, the central thrust of any attempt to retool the education system must involve expanding access to communities (of practice) not simply to credentials. "The purpose of retooling must be two-pronged-it must seek to provide wider access to communities, but it must also expand ways to represent new forms of access in the markets where students need exchange value." (i.e. new forms of credentialing)*

Universities are built around overlapping communities that create, disseminate, and preserve knowledge and practice (explicit and implicit knowledge). I will use the phrase "knowledge community" as shorthand for "communities that create, disseminate, use and/or preserve knowledge and practice." A university-based knowledge community does not necessarily mean a community of peers. It can include, as it usually does, members across a spectrum of expertise – Nobel Laureate to neophyte. People may also play different roles in different communities – teacher in one and learner in another.

The key point here is that any appropriate figure of merit on the use of ICT in higher education has to have something to do with enabling or enhancing members of communities of knowledge and practice to interact with each other, and with the information and tools of their trade. And members and institutional affiliation of these communities can be diverse: observer, student, teacher, researcher, and practitioner.

2.3 ICT as infrastructure (cyberinfrastructure)

The term "cyberinfrastructure" has recently come into use to describe the combination of information and communication technology (ICT), service organizations, human resources, and policy that under gird an increasing range of knowledge-based activities in society. The term infrastructure is a reminder that revolutionary, or even incrementally effective application of ICT requires more understanding and effort to define, build, and sustain a true infrastructure layer for ICT. Infrastructure is itself a complex subject. By definition it includes facilities and services that are largely taken for granted until they are missing, but it is often the most complex and expensive undertaking of society. The prefix "cyber" denotes the emphasis on ICT-based infrastructure, both hardware and software. It is also a reminded that ICT-based infrastructure is different from bricks and mortar "built" infrastructure. On the negative side it depreciates more rapidly; on the positive it offers new possibilities for sharing and reuse of facilities and enables new distributed organizational forms.

Figure 1 illustrates functional capabilities of cyberinfrastructure as defined in a report released in February 2003 by the U.S. National Science Foundation (NSF) entitled *Revolutionizing Science and Engineering Through Cyberinfrastructure* [16]. The report develops a vision of a comprehensive, advanced IT-based infrastructure that is becoming a platform for new methods and organizations for scientific and engineering research and education. Terms such a *collaboratory*, *grids*, and *e-science* are used for these new organizations, many of which are virtual and geographically distributed. They potentially support participation anytime, anyplace, and by anyone. The report finds,

> *…that a new age has dawned in scientific and engineering research, pushed by continuing progress in computing, information and communication technology; and pulled by the expanding complexity, scope, and scale of today's problems.*

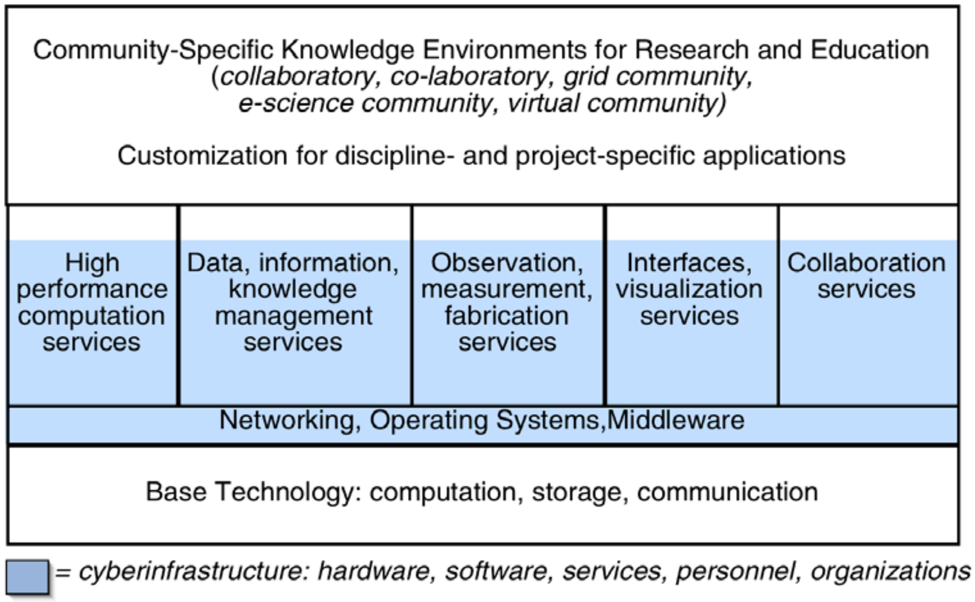

Figure 1. Cyberinfrastructure services.

The major components of cyberinfrastructure include:

1. **High performance, global scale networking** as a hybrid of traditional packet switching and the newer point-to-point optical "lambda" networks.

2. **A special type of software called "middleware",** that makes it much easier to build community specific, inter-institutional virtual organizations in efficient, secure, and trustful ways. In the education community the emphasis is on middleware based on open standards and open source software. Important middleware initiatives include [17, 18]

3. **High performance computation services** capable of simulating complex phenomena such as galaxy formation or social-physical models of global warming.

4. **Data, information, knowledge management services** federating vast networks of digital libraries, archives, and museums (LAMs) providing content and sustainable knowledge management services. They include comprehensive collections of literature, data sets, and a large variety of multimedia objects. Preservation, interoperability and re-use of scientific data is a high priority in many research communities and there is a growing unmet need for people and institutions to provide long-term curation and preservation.

5. **Observation, measurement and fabrication services** including arrays of networked scientific instruments and sensors to measure and observe our world and beyond.

6. **Interfaces and visualization services** to support interaction between humans and the ICT environments in ways that are natural and exploit the full range of human sensory capabilities.

7. **Collaboration service** to enable distributed teams to work together as well or even better than they can in physical proximity;

Cyberinfrastructure initiatives by various names are now underway in most all countries in the developed world. Examples include UK e-science [19], Canadian CANAIRE "Third Wave," European Union 6^{th} Framework [20], South Africa CSIR [21], and the Japanese Earth Simulator [22] (primarily a computation initiative). The initial focus is on research and educations in science and engineering but these fields are usually at the forefront in creating and adopting ICT and thus the cyberinfrastructure movement is likely a harbinger of much broader impact on research, learning and societal engagement. In the U.S. the American Council of Learned Societies (ACLS) has commissioned a panel to study the impact of cyberinfrastructure on the humanities and the less quantitative social sciences. The panel's report is due in early 2005 and is chaired by Professor John Unsworth (unsworth@uiuc.edu) at the University of Illinois. The recent survey of "cyberscience" by Nentwich [23] complements the NSF cyberinfrastructure report, but because it uses the broader notion of science embodied in the German word *wissenschaft*, it also complements the humanities study.

3 Some properties of cyberinfrastructure-enhanced knowledge communities

Cyberinfrastructure is a layer of ICT-based services, institutions, and human resources on which are built specific environments to support knowledge communities for research and education. We use the phrase *cyberinfrastructure-enhanced knowledge communities* (CKCs) as the generic name for these environments. The specific terms collaboratories, e-science, and grids are now used for CKCs and the science and engineering research communities are now the pioneers in building and using them. But the perspective of this paper is that these activities are the vanguard for broader adoption of cyberinfrastructure in support of higher education. What are we learning in the context of scientific research can help build vision and scenarios of broader use. In this section we outline some of the general properties and possibilities.

3.1 New tools

Cyberinfrastructure provides new tools for exploration, creativity, and inquiry-based learning. Examples include computational simulation, composite instruments, data mining, virtual and augmented reality, new document genres, and push and pull information sharing. These tools are powerful when used alone but even more so, as we will discuss shortly, when combined into functionally complete "collaboratories."

Computational simulation is now widely regarded as a third mode of science together with theory and experimentation. It is the tool for modeling and understanding the formation of the universe, global climate change, and predicting and protecting against natural disasters. Observational platforms (e.g. telescopes, satellite-based instruments, sensor arrays, ocean research ships) become new, more powerful *composite instruments* when linked together over networks. *Data mining* techniques enable reuse of data sets to find information not expected when the data was acquired. *Virtual and augmented reality* offer immersive interfaces between humans and computational systems. Virtual reality is a product of total digital synthesis of sensory experiences and augmented reality is a composite of the synthetic and observed world. The digital realm also enables *new genres of multimedia* documents blending text, image, audio, video, and computation applets. And these documents can now be disseminated to the world at essential zero incremental world and in a complex distribution environment of both push and pull between producers and consumers.

3.2 Relaxed constraints of time and distance

Figure 2 is a two-by-two matrix representing the four possibilities for interaction in same and different, time and place. There are three types of interactions denoted: people-to-people (P), people-to-information (I), and people-to-facilities (F). Facilities include instruments and machines for observation, measurement, fabrication and robotic assembly. Although not explored here, it is also possible for information and facilities to interact with each other without human intervention.

Geographic Place \ TIME	Same (synchronous)	Different (asynchronous)
Same	P: Physical mtgs. I: Print-on-paper books, journals F: Hands on labs, shops, studios	P: Shared notebook I: Library reserves F: Time-shared labs, shops, studios
Different	P: AV Conference I: Web search F: Online, real time instruments	P: Email I: Knowbots F: Autonomous instruments, session objects

Figure 2. Examples of human, information facilities interaction over time and place.

The upper half of Figure 2 is the zone of interaction and collaboration for the traditional place-based educational institutions. Members of knowledge communities interact with each other, with print-on-paper objects and with facilities, all in physical proximity (upper left). The interaction can also be distributed over time by sequential use (time sharing) of a physical location, information objects, and facilities (upper right). Cyberinfrastructure can be used to augment same place interactions, but the greatest new potential comes from communication and storage capabilities that enable geographically distributed synchronous and asynchronous interaction. This is the “anytime, anyplace” attribute.

The examples in the lower left are self-explanatory. In the lower right quadrant “knowbots” is a popular phase for software intelligent agents that locate, summarize, and notify their human customers of information they have been trained to recognize as relevant to them. Similarly there are autonomous scientific observational platforms. “Session objects” refer to digital streams archived for replay and reuse as science teams conduct scientific experiments. Peers and students can visit the session later to review, learn, comment, and annotate.

The “any time and any place” attribute creates a basis for participation by anyone. This enables broaden participation by other than the usual members of a university community. Government officials in a developing country could both learn and make unique contributions to a graduate seminar on the topic of ICT and globalization. Mechanical engineering faculty, students, and practicing engineers from Korea, the US and Germany and the Netherlands could undertake a global product design course. Amateur astronomers could use and contribute data to the “digital sky” database of the emerging network of national virtual observatories [24].

We conclude this section my emphasizing that we are *not* advocating that higher education move completely into cyberspace – into the lower row on figure 2. The point is that cyberinfrastructure offers the opportunity for the processes of learning, engagement, and research to occur through a traversal of all four quadrants of figure 2. Activities in physical proximity will continue to be important (distance does matter) but it may be appropriate to use it differently. (There are also circumstances in which cyberinfrastructure can provide experiences “beyond being there.” [25]) Some faculty are now delivering their lectures asynchronously through the web and then using the same time and place classroom for interactive discussion. As noted by Margrethe Vestager in an early OECD meeting on the future of higher education, same time and same place may become the most precious quadrant for knowledge communities to work in and it needs to be treated accordingly. Higher education will not vanish into cyberspace but those institutions that do not fully explore the use of all four quadrants of figure 2 will likely lose competitive advantage to those who do.

3.3 Functional completeness

Some research communities are now using cyberinfrastructure not simply to automate what they have always done, but rather to open fundamentally new paths of research and learning – to do new things in new ways. It has become a first-class tool for science. The ATLAS Experiment for the Large Hadron Collider [26] centered at CERN could not, for example, be done without advanced cyberinfrastructure. A few of these cyberinfrastructure based research communities are becoming *functionally complete* in the sense that all the colleagues, all the tools, all the instruments, and all the literature, and data that the research community needs are available through the Internet. Although a major challenge to achieve, we expect this trend to continue and thus people not connected to their field's Internet collaboratory, or not fluent in using it, could be excluded from the first-tier research communities. But on the more positive side, functionally complete collaboratories offer the potential for many more people to participate in first-rate research and learning communities on a global scale.

3.4 Comprehensive and potentially more open access to information

The most visible impact of the digital age is access to data and information. Data or information born or converted to digital form takes on many new properties not possible with print-on-paper and analog representation. It can be stored at atomic scales of density; it can be moved around the world at the speed of light; it can be combined into new multimedia genres including text, images, video, audio, and computational applets; it can be enriched with metadata and hyperlinks; it can be perfectly reproduced and distributed at negligible incremental cost, and it can be "read" and computed over by machines as well as humans. Although many social and economic barriers remain, a true global information infrastructure is within reach [27, 28]. The recent introduction of the Goggle Scholar and announcement of a partnership between Google and major research libraries (Stanford, Oxford, Michigan, Harvard, and New York Public) to digitize the complete holdings over the next five years is accelerating the realization of a complete digital information environment. Other mass digitization projects are also underway.

The digital world creates intrinsic forces of convergence and blurring of boundaries in information genres, institutions and practice. Digital representation converges text, images, audio, video, simulations, and other computational objects. Users will expect the distinctions between libraries, archives, museums, data archives, and "institutional digital respositories" to blur – they will want all to be online and objects from any of them to be found by an appropriate topical query. A single query might yield in a convenient federated way books about George Washington, a copy of his first inaugural speech in his own hand, model of a writing desk from Mount Vernon, a class lecture by a prominent Washington scholar, and weather data for the city of New York on April 30, 1789.

Digitization of information is necessary, but generally far from sufficient to enable widespread access and use. There are issues of access to computers, networks and mastery of necessary skills; there are technical issues of how to federate, search and display digital collections that are geographically and administratively distributed; and there are issues of intellectual property rights and commercial interests. All of these, but particularly the later, can work against the potential for universal access to comprehensive collections of information and data. Complex sets of forces are at work and experiments underway to define the balance.

The entertainment industry, frightened by experience with peer-to-peer file sharing (Napster, et. al.) have mounted an aggressive "digital rights movement" [29] to secure broad legal and technical protections on digital media including hardware modifications to media players. The traditional scholarly publishing industry has been licensing digital collections to libraries with terms under which the libraries cannot guarantee future access to collections if they terminate an annual subscription. Commercial copyright holders have taken very conservative positions on digitize versions of their holdings and on policies of fair use. And the extension of copyright duration in the U.S. has largely eliminated the traditional notion of public domain [30], and the translation of the original intent of copyright to the digital age is not, in many expert's opinions, going well [31].

But there is also an "openness movement" building within academia that gives reason for optimism about new ICT models of scholarly communication emerging that could lead towards more open at least for academic literature. Digital publishing through the web eliminates the upfront, fixed-cost of printing and distributing ink on paper. It also enables new multimedia formats that are born digital; that may include audio, video, data sets, and interactive programs that have no print-on-paper equivalent. It blurs the distinction between libraries, clients, and publishers and potentially disaggregates the stages in the life cycle of information creation, access, use, and re-use. Several trends are noteworthy:

1. Serious exploration of open (free) access to well-credentialed publications in which authors do not give away their copyright to commercial publishers who sell them back to libraries at high profit margins. A good example is the Public Library of Science. [www.publiclibraryofscience.org]. Recently Springer, the world's second largest scientific publisher announced adoption of Open Access (OA) publishing. Springer Open Choice allows authors to choose to pay $3000 for OA print and online publishing. [Information World Review http://www.iwr.co.uk/iwreview/1156517].

2. Evolution of alternate licensing models for digital objects that help re-establish a public domain of resources and encourage their creative use in derivative products. Creative Commons creativecommons.org is at the forefront of this movement. It is "devoted to expanding the range of creative work available for others to build upon and share."

3. Shift to work flow models in scientific research that produce and share more intermediate products on the path to refereed, archival publications. The pre-print server movement is one example, and examples of preprint or e-print servers are easily found with a Google search on these terms.

4. Establishment of "institutional repositories" that more reliably capture, organize, and preserve the digital information products of a university or other knowledge-based institution. The D-Space Project, now becoming a federation of

respositories, is a seminal example at www.dspace.org. A special case of an institutional repository is the MIT Open Courseware Initiative (now becoming a consortium with other schools) that is offering MIT course material free to the world.

5. Scientific research communities, especially in genomics and geosciences are now cooperating on creating community databases as well as open source community computer codes that are intended to be both built and use by broad communities.

A report for a 2004 symposium at the U.S. National Academies on *Electronic Scientific, Technical, and Medical Journal Publishing and Its Implications*, discusses many of the developments, challenges and opportunities for scholarly communication in the digital age. It is available at The National Academies Press at www.nap.edu.

3.5 Examples and places for further information

The NSF cyberinfrastructure report [16] includes many examples and references to the application of cyberinfrastructure to the creation of collaboratories, grids, and e-science communities. Other supplementary sources on both the technical and social dimensions of CKCs include [32-36]. To convey a more tangible idea about the effect of a CKC on the practices of a specific science research community we conclude this section with a bullet list of vignettes of payoff from a ten year collaboratory experiment with a space physics and upper atmospheric research community funded by the NSF and centered at the University of Michigan. More details on the Space Physics and Atmospheric Research Collaboratory (SPARC) is available at [37].

- Shared, tele-instruments and sharing of expertise on their use;
- Rapid response to unexpected natural events (e,g, solar flare) and ability to mount opportunistic data gathering campaigns;
- Multiple instruments and eyes on the same events and increased fusion of complementary expertise;
- Previously isolated observational instruments federating into a global scale observational platform;
- Enhanced cross-mentoring/training between team members (faculty and students);
- New & earlier opportunities for grad students to interact with and be known by the leaders of their field;
- Enhanced participation by faculty and students at other than the lead institutions; support for "legitimate peripheral participation;"
- Used to provide authentic, inquiry-based learning in undergraduate and pre-

college level geo-science courses;

- Supported distributed workshops for post-campaign data analysis;
- Enabled data gathering session recording and re-play for delayed participation by others around the world and supported hand-off of experiment management to in normal working hours around the world;
- Data-theory closure – built deeper ties between the experimentalists and the theoreticians/modelers (models were run in data campaign to predict where to steer the instruments for more effective observation);
- Provided a "living specification" to stretch vision of possibilities for others.

4 Possibilities and Issues

4.1 Possibilities

In the previous sections we have sketched some of the trends around ICT and its embodiment as "cyberinfrastructure," and summarized some of the key generic features of cyberinfrastructure-enabled knowledge communities. The emerging picture is one in which cyberinfrastructure becomes a powerful platform for supporting the fundamental mission of higher education in learning, research, and societal engagement but doing so to a large extent by providing more resources and opportunities to *individuals* and the *communities that they choose to form and join*. It enables a dynamic web of virtual communities cutting across traditional institutional boundaries. These communities, as they become functionally complete, may well become the "real" communities --- the place one needs to be to participate at the frontier of their discipline. Cyberinfrastructure helps create the conditions for a learner-centered approach to education that build synergy between 1) learning inside the formal classroom; 2) learning outside the classroom through engagement with diverse cultures and contemporary societal problems; and 3) research and other creative activities at all student levels.

The empowerment of students and faculty to pursue their goals outside the walls and structure of the institution raises questions about the obligation of institutions to provide such infrastructure and about the associated threats to the status quo. It also raises questions about the obligation of the institution to fully embrace the technology and to become an ecology of experimentation on how to use it to better carry out their mission. The masterful creation of experiences and the reputable credentialing of mastery of knowledge and skills will, for example, continue or likely increase in importance.

James Duderstadt[2] provides several more specific examples to illustrate important potential paradigm shifts:

[2] Personal communication with author.

1. Globalization of research activity, as new collaborations enabled by cyberinfrastructure compete with traditional organizations such as the research university for the loyalty and participation of scholars.

2. Newly emerging research communities that compete with and break apart the feudal hierarchy that has traditionally controlled training (particularly doctoral and postdoctoral work), empowering young scholars and enabling greater access to resources and opportunities for collaboration and engagement.

3. The impact of cyberinfrastructure on the "culture" of scholarly activities and institutions, e.g., publication, collaboration, competition, travel, and the ability of participants to assume multiple roles (master, learner, observer) in various scholarly communities, the increasing importance of creativity relative to analysis as powerful new tools of investigation (e.g., simulation, massively pervasive sensor arrays) that are enabled by cyberinfrastructure.

4. At its most abstract, the "university" is a community of masters and scholars (*universitas magistorium et scholarium*), a school of universal learning, that embraces every branch of knowledge and all possible means for making new investigations and thus advancing knowledge. These two characteristics, scholarly community and breadth of both intellectual topics and tools, have remained the core elements of the various forms taken by the university from medieval times (e.g., Paris and Bologna), through the Renaissance and Enlightenment, to today's research universities. We already see these elements appearing in new forms enabled by cyberinfrastructure, e.g., global, domain-specific communities of scholars detached from traditional institutions such as universities, and exceptionally broad digital collections of knowledge such as digital libraries or the archives of search engines such as Google. Could these be the precursors of a new form of the university (perhaps a truly world university), essentially appearing spontaneously out of the vacuum state of the cyberspace enabled by cyberinfrastructure?

4.2 Issues

We conclude with a list of topics and issues to initiate reflection and conversation among convened experts on the topic of ICT and the future of higher education.

1. **How do we make the opportunities and threats of CKCs more visible and compelling enough to gain the attention of leaders and to mobilize timely action? How will we align the necessary stakeholders and construct the case for investment?**

   Although as mentioned in the first section, there are growing deliberations and writings of the topic of ICT and the future of higher education, it has not in general translated into strategic and systemic action by the leadership of higher education. What further should be done, especially to explore the international and global scale implications? How do the opportunities afforded by CKCs relate to the European Higher Education area (EHEA) Bologna process and the European Research Area (ERA) initiatives?

In particular the next phase of the scientific research "cyberinfrastructure movement" needs to engage the various stakeholders of science and technology, and help them to understand the opportunities and challenges presented by rapidly evolving digital technologies. While research agencies can provide leadership and seed important efforts to build and exploit cyberinfrastructure, it is critical to engage those institutions such as research universities, corporate R&D organizations, and national laboratories where scientific research, training, and application actually occur, since this is where the greatest impact of–and the greatest commitment to invest in–cyberinfrastructure will occur. So too, those stakeholders dependent upon the application of science and technology such as industry, government, and education will be strongly impacted by cyberinfrastructure (e.g., through the availability of scientific knowledge, the collaboration of researchers with practitioners, the increasing pace of scientific discovery and application) and hence need to both informed and engaged.

Since cyberinfrastructure is of major importance to a broad array of science and technology activities (research, training, application) and institutions (government agencies, universities, industry), it is important to stimulate conversations among the various stakeholders so that both understanding of key issues and development strategies are coordinated to some extent. How do we do this?

2. **How do we organize and finance the building and sustaining of the appropriate common cyberinfrastructure?**

Even though there is a growing consensus that R&D investments in ICT provide high return on investment and that additional investment is needed to build and sustain cyberinfrastructure and related services, at least in the U.S., very little new money has been allocated to this goal and the near term prospects for incremental funding are not good. The same is generally true in state supported institutions and is part of the general paradox that just as we have unprecedented opportunities to reinvigorate, even revolutionize education, the public has never been less willing to invest in education as a public good. Is there any way to reverse this, at least with respect to creation and innovative application of cyberinfrastructure? Do we need a short, compelling "moonshot goal" to galvanize interest and create willingness to invest? If so, what is it?

ICT offers the potential for providing better and even new services at lower cost but getting to this point generally requires additional investment and a long period of funding for both the old and the new before reallocation of funding is possible. A prime example is the JSTOR project [www.jstor.org] initiated by the Andrew Mellon Foundation. The project has created a reliable and warranted service for providing higher education long-term access to digital versions of complete back issues of core academic journals, especially those appropriate for undergraduate work. The access through web portals and powerful search engines is much more effective than going to a physical library. A goal of the project is to enable many academic libraries to stop storing back issues of journals, to reallocate funding to other activities, and to avoid the need for more bricks and mortar. But the trust of the system to give courage to librarians to dispose of their paper is just barely starting.

But even if new funding is secured there is still the complex issue of how higher education will come together to create and sustain a cyberinfrastructure (based upon open standards and perhaps open source middleware) that enables virtual communities to interoperate across institutional and national boundaries. There need to be agreements and trust built for distribute support and sharing of information and other resources for the common good. There need to be new or re-charted consortia. From where will leadership come for such an undertaking?

3. **Were do we find the human resources with command of the complex array of social and technical issues around building and managing CKCs? What training and incentives are needed for academic communities (faculty and students) to adopt new paradigms?**

   The creation and management of CKCs require professionals that combined competence in the technical and social issues of these new organizational forms as well as some fluency with disciplinary activities in supports. Faculty and students must also have opportunities for retraining and experimentation.

4. **What is the new balance between inter and intra institutional cooperation and competition implicit in CKCs? How will we create incentives for giving and taking and supporting common infrastructure for the common good?**

   One of the most pervasive influences of ICT on all knowledge-based organizations, including higher education, is to change the boundaries between cooperation and competition within and between organizations. Higher education needs to cooperate in creating and sustaining a shared cyberinfrastructure for the common good. The cyberinfrastructure will then be a platform for new structures of cooperation and competition between distributed teams of researchers, learners, and practitioners.

5. **If cyberinfrastructure does in fact enable broader participation in higher education, what is our societal responsibility to use it this way? How do we make high quality educational opportunities available to the "bottom of the pyramid?" Do universities need a stronger global presence in order to truly be universal and strive for uni-versity (unity from diversity) in the digital age?**

6. **Given the increased reach and connectedness and the need for co-investment on shared resources what type of alliances make sense and how do we approach forming them? What about international alliances?**

7. **How can we change the model of education from teacher-centered to learner-centered (from producer to consumer driven) and what role do CKCs play in this change.**

   Although it runs against the grain for faculty control, some major universities are mounting strategic programs to more intentionally move to a learner-centered culture. The University of Southern California (USC), for example, has created a new Vice-Provost to oversee such initiatives and includes the following in the job description:

   The learner-centered university focuses on the educational needs of the student rather than the structure and needs of the teaching university. Learner-centered education enhances classroom teaching with new pedagogical approaches and the use of technology, engages students outside the classroom in experiences that connect learning to contemporary problems, and offers significant research opportunities to students at all levels. Integrating classroom experiences with research led by renowned faculty offers learning opportunities rarely available in major research universities, especially at the undergraduate level. Learner-centered education at USC will increase the level of academic challenge, promote active and collaborative education, increase student and faculty interaction, enrich educational experiences, and provide a supportive campus environment. Students will graduate with skills in critical thinking, analytic reasoning, and strong written and oral communications. The environment will attract prospective students at all levels and improve retention.

8. **What are the potential tradeoffs between built infrastructure (bricks and mortar) and cyberinfrastructure on the structure of the campus? Can the capital and increasing recurring costs of the physical plant of universities be reduced through greater adoption of cyberinfrastructure? How should new buildings be designed or old buildings renovated to create more harmony between the physical and virtual communities; between local and remote resources?**

9. **How do we evaluate the impact of CKCs in learning, research, and societal engagement and feed it back into a process of iterative design? What emerging deeper understanding of human learning can inform the design and evaluation of CKCs?**

10. **Can CKCs be critical in achieving lofty aspirations such as**

    a. improving equity of access to higher education;

b. opening up the opportunity for more experiences and increasing the probability for discovery in the “white spaces” between disciplines;

c. enriching the diversity of participation, perspective, ideas, and experiences;

d. enabling sharing of resources and greater amortizations and leverage on resource/facilities investments;

e. supporting both existing teams and communities, as well as accelerating the formation of new teams, fields, disciplines;

f. supporting rapid formation of teams of complementary expertise to respond to unexpected emergencies such as a SARs outbreak.

11. How does use of cyberinfrastructure relate to potentially radically different post-secondary systems?

To diversify the perspective I am reproducing, *especially for consideration in the context of the opportunities afforded by cyberinfrastructure-enabled knowledge communities*, the following provocative questions proposed by Martin Wolf, associate editor and chief economics commentator at the *Financial Times*, in the aftermath of a previous OECD sponsored workshop on alternate futures for higher education.

a. Can we envisage some fundamental changes in the education systems as a whole? Could we, for example, envisage a complete shift away from public provision of primary and secondary education? If we did, how might this affect tertiary education?

b. How far can we envisage a world in which undergraduate education becomes universal and is provided in the same way as secondary education is today – that is by people who are entirely teachers, not researchers, and are employed exclusively by the state?

c. If research functions moved entirely into separate institutions from those providing undergraduate education, can we envisage these functions being separated even from most post-graduate education?

d. Can we alternatively imagine the entire privatisation of university education, with the state playing a limited role in financing students (probably through loans) and supporting specific research projects?

e. How far can we envisage education being life-long, with people taking up entirely new careers in later stages of life? How might the university system adapt to such a change?

f. Can we envisage the globalisation of universities? Could institutions move increasingly outside national systems? This has already happened with some business schools. How far might this go? Would there then be a global elite system on top of national non-elite systems?

g. Even if we did not imagine such globalisation, how far can the export of university education go? Could we imagine a time in which the majority of students in most top-rate universities in OECD countries were foreign?

h. Can we imagine a total separation of the different intellectual strands in the contemporary universities, with humanities in different institutions from science and social science, instead of the comprehensive institutions we have today?

i. Can we image a situation in which scientific research and corporate research were almost completely fused? What impact might this have on the independence of universities?

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