Leading Cyberinfrastructure Enterprise: Value Propositions, Stakeholders, and Measurement*

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Introduction

"Cyberinfrastructure" or CI as used in this paper describes the digital infrastructure for scientific endeavor. It is at the heart of changing practices in science. The impact of CI spans energy, finance, health, humanities, information, environment, security, transportation, and other core aspects of the human condition. Many defining technologies and practices have roots in CI: the Internet, open source software, cloud computing and "big data" are but a few examples. The leadership of CI enterprises – the organizations that develop and support CI – know the value of CI, but have trouble communicating this value to others. Further, there are operational challenges around attracting, developing and retaining the workforce essential for success; serving an increasingly diverse array of customers and users; and operating in the context of a changing social contract with key sponsors and stakeholders.

An NSF-funded workshop was held at the University of Michigan in Ann Arbor on February 15-16, 2013. The workshop brought together CI enterprise leaders with organization scientists to discuss the value and operation of CI enterprise in the face of uncertain funding, ongoing change in technology and other factors, "benchmarking" with respect to peers, and similar concerns. Collaboration between CI enterprise leaders and organization scientists has potential, as in the study of the impact of organizational practices on innovation and knowledge creation. However, the interests of these two communities is seldom well aligned (Berente et al 2012). The workshop sought to explore what stakeholders from these communities need and want from collaboration. Improving understanding and communicating of CI's value was the objective. This report explains what was learned from the workshop, and what might be done to help CI enterprise leaders.

Concerns of Cyberinfrastructure Enterprise Leaders

CI enterprises often bridge between science communities, providing support beyond that available from desktop or laboratory equipment. They offer access to local, regional, national or international CI resources. Managing and using CI enterprise requires border-crossing: contracting for support, adherence to conventions and rules of various providers, close interaction with experts elsewhere to determine whether the technology can support a given project, and if so, how to make that support successful. Arrangements must be made, implemented, and sustained. Needs are often idiosyncratic to the research being done, and a lack of commercial, off-the-shelf solutions requires customization – often on a shoe-string. CI enterprises are hotbeds of innovation in digital technologies. They experiment with new forms of engineering and computing, and new organizational and institutional arrangements. CI enterprises embrace and sustain continuous innovation. The World Wide Web that changed the way we live and work grew out of efforts originating at CERN and built upon by NCSA and other well-known CI enterprises.

Cyberinfrastructure is about *infrastructure* that is embedded in ongoing activity. Once routinized, infrastructure is often forgotten, sedimented, and attention is tied mainly to breakdowns (Star and Ruhleder, 1996). CI enterprise innovations enable new science, but CI enterprises themselves must be stewards of established, essential infrastructure, navigating the tensions of competing standards, platforms, and capabilities. CI enterprises continue to persist and often grow since large-scale science projects require CI support of the kind provided by the large centers.[1] However, the funding models under which these centers were established have changed or likely will change, and the question of the value of CI enterprise is important.

General principles of administration are important to CI leadership, ranging from human resources, to budgeting and project management. Moreover, there is a big difference between managing projects and managing persistent organizations. CI leaders, and scientists in general, are good at project management, but it takes a different set of practices to run a persistent enterprise that manages a portfolio of projects within an enterprise over time that makes best use of resources. Individual grant-funded projects wax and wane, but CI enterprises must maintain core capabilities and continuity of enterprise over time. As expressed by one CI enterprise leader, management or leadership education is “treated as finishing school rather than core to science.” In other words, CI enterprise leaders do not have much chance for such education.

CI enterprise leaders also expressed concern about losing talent to firms such as Google, Amazon and others. The intrinsic rewards of working in science helps CI enterprises to compete, and often helps with retention of younger staff members because the “jobs are exciting.” But this alone does not address the overall challenge. Another human resource concern is the uncertainty of grant funding. When a grant ends staff might wait for short periods for other grants to come online, but the way grants are awarded can create difficult dynamics such as the a see-sawing of support that increases startup costs, undermines long-term stability, and impairs organizational memory. Staff turnover is a dominant concern among CI enterprise leaders. When good people leave the enterprise faces a real burden of talent loss and replacement.

A major concern of CI leaders that does not fit with general administration is a perceived change in social understanding of the value of science itself that places downward pressure on science funding based on long-term payoffs where much of the value of CI enterprise lies. Technology startups might be in “stealth” mode for years, building on basic science and creating the right conditions for launch. When the right time comes startups can produce what appears to be immediate returns. Society seldom sees the basic science behind such returns, and comes to expect exciting results quickly. CI enterprise leaders know that their enterprises are supporting cutting-edge science, but it is hard to communicate this value to the broader set of stakeholders they must now engage. Discussing their contributions in terms of inputs such as “floating point operations per second” (FLOPS_ provided or services used such as utilization percentages does not work. They need better measurement and communication of the value of CI enterprises. The next section addresses this need.

[1] Such as the centers in attendance at this workshop: NCSA, SDSC, PSC, RENCI, NICS, NERSC, EMSL/MSCF.

Challenges in Measuring and Communicating CI Value

CI investment has been justified on needs of particular scientists for the “third pillar,” computational science in addition to theory and experiment. CI was often funded using the “Field of Dreams” approach - if you build it, research will come (DeMillo 2013). Quite often this worked out, but CI enterprises must increasingly justify themselves to a growing array of stakeholders who want to understand the levels of CI enterprise impact and the dimensions and measures of value. We use the “Capability Maturity Model” for software development to address levels of impact, and explore measurement of value across four dimensions that CI enterprise leaders might consider.

Applying the Capability Maturity Model

The Software Engineering Institute at Carnegie-Mellon University has developed the Capability Maturity Model for software development. This can be more broadly adapted to CI enterprise. There are four levels, each building on the previous level and improving enterprise operations and communication.

- Level 0 - Measure and communicate resources and capabilities enabled
- Level 1 - Measure and communicate resource utilization
- Level 2 - Measure and communicate scientific impact of utilization
- Level 3 - Measure and communicate broader impacts of all enterprise operations

Level 0, depicted below, describes enterprise activities as resources made available (e.g., number of FLOPS or bytes of storage in the case of computational resources, or skill sets in terms of human talent). This might cover the number of lines of code developed, the different versions released, the number of people available for a function like the help desk. Such operational metrics might be useful for informal internal discussion among enterprise employees, but say little to many of the enterprise stakeholders.

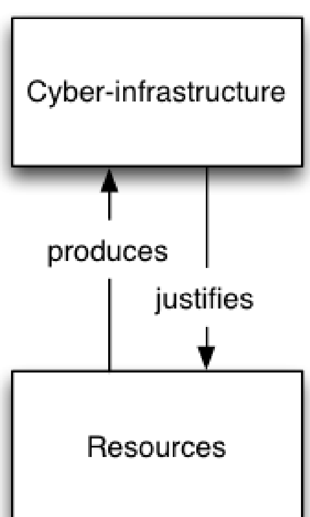

Figure 1: Level 0 Value

Level 1, depicted below, measures the extent to which the cyberinfrastructure resources are used by the scientific community. Metrics extracted from "accounting" systems such as the number of CPU hours consumed, the number of software downloads, or the number of problems resolved can be broken down by users or scientific fields. This has some use to stakeholders who understand how the work is done, but it is of little use conveying value to other stakeholders.

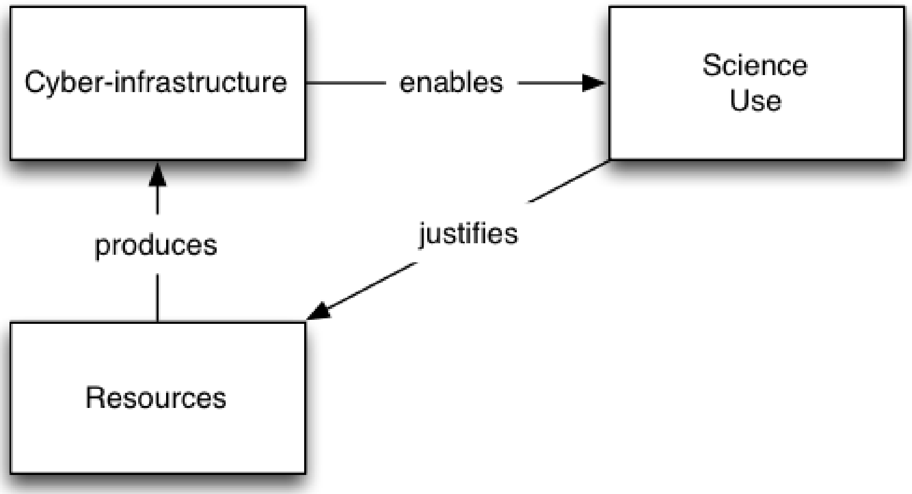

Figure 2: Level 1 Value

Level 2, depicted below, seeks to measure and communicate how the use of the CI enterprise resources benefits the science that is done. A common measure for this is the number of research publications produced from results facilitated by the enterprise. "Science cases" – narratives of how the cyberinfrastructure contributed to science findings, often accompanied by vivid images – are also used for this.

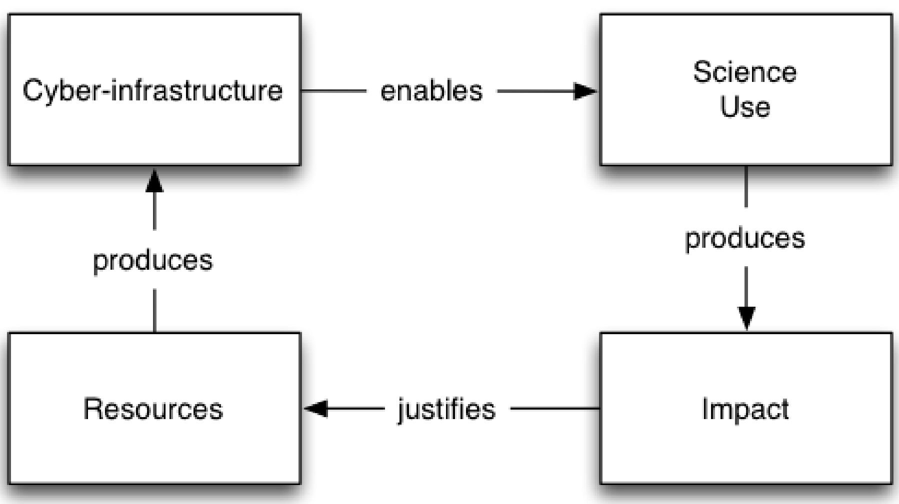

Figure 3: Level 2 Value

Level 3, depicted below, involves a broader discourse for measuring and communicating impacts, both indirect (deriving from science facilitated by the enterprise) and from an enterprise's direct activities. This requires two shifts: differentiating among stakeholders and a change in the focus of CI enterprise leadership from particular projects to the CI enterprise itself. CI impact on science cannot, by itself, justify the CI enterprise. Educational, innovation, and economic returns are important to many CI enterprise stakeholders.

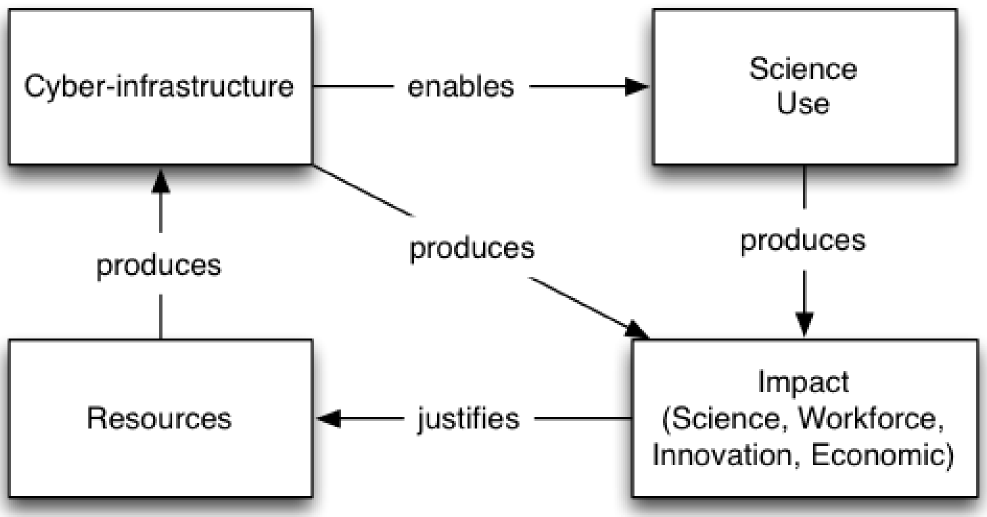

Figure 4: Level 3 Value

CI enterprises are often adept at Levels 0 and 1 (resources and utilization). Some touch the surface of Level 2 (direct output on scientific findings). Few reach Level 3 (indirect effects on innovation, workforce, and economic outcomes). Why? In large measure this is due to the fact that CI enterprise leadership did not have to worry about this until relatively recently when the stakeholder ecology became more complicated.

CI enterprise leaders need to become adept at stakeholder analysis. Stakeholders include anyone with a "stake" in the enterprise, whether they know it or not. Stakeholder analysis identifies stakeholders and assesses their interests, perceptions, and behaviors. Techniques such as interviews, surveys, workshops, and observation can be employed. A value proposition should be created for each stakeholder, and a process established to measure and communicate the value to the relevant stakeholder. The enterprise's value is the benefit it provides for its set of stakeholders. Different stakeholders benefit in different ways, so value propositions must relate to a particular stakeholder. The interests of stakeholders should not be conflated by accident. The U.S. House of Representatives and federal science funding agencies such as the National Science Foundation and the are part of the federal government but their interests as stakeholders might vary greatly. Science funding agencies might care about specific scientific findings, while the House might care about return-on-investment in innovation, workforce development, or national security. Individual members of Congress might be their own stakeholders.

We identify four dimensions for CI enterprise value propositions: science, innovation, workforce, and economic:

- **Science** - Stakeholders might be interested in different elements of science, measured in different ways. Scientists who need CI resources are obviously science stakeholders. CI enterprises have worked with them for a long time, so those stakeholder needs tend to be well covered. Workshop participants identified three additional stakeholder groups as important for science: federal funding agencies, the general public, and local university administrators. Funding agencies consider publications and citations as "currency of the realm." The general public (including Congress) often understands scientific impact through rich case descriptions. University administrators might use the amount of funding obtained or publications and citations to show how strong they are in research. Unfortunately for CI enterprise, just because CI is involved in the scientific endeavor does not mean that the science would not have happened without CI. Simply understanding the "science" stakeholders has become more difficult than it once was.

- **Innovation** - Many innovations (technologies, startup organizations, new industries) have roots in CI. Measuring patents and university technology transfer seldom communicates the impact of such innovation over time because the real value of innovation unfolds over time and that is hard to measure. Irrespective of this problem, the demand for innovation is growing. Improved means for measuring this are needed.

- **Workforce** - CI enterprises can produce workforce effects by creating new job opportunities. Their relationships with universities often allow them to tap into student populations and provide valuable experience with high-performance computing, big data, software development, or other activities important to industry. "Extreme-level" experiences with supercomputers, massive datasets and related complex problems can create an important workforce benefit rarely touted from CI enterprises that see the production and placement of highly experienced personnel as "routine," or even as a loss of talent rather than a "skilling-up" of the broader societal workforce. This "diaspora" phenomenon will be discussed below.

- **Economic** - Science has had significant economic impact over longer time horizons. Innovation and workforce outcomes might take place in intermediate time-frames. Direct return-on-investment (ROI) can be harder to measure, but many stakeholders would like to see this from science. Economic return to the institution or region, often measured by income from federal grants, might be used to show direct return. CI enterprises that work closely with industry might claim some industry revenues. In any case, CI enterprise leaders must become more skilled at discussing ROI with stakeholders. Tangible measures are needed, but they are hard to find. Economists look at overall economic return of science and technology spending, but each of these measures is quite complicated, contextual, laden with assumptions, and very sensitive to timing of analysis (Lane 2009; Link & Scott 2012). At present there is no simple, single measure for science ROI. In some cases the ROI appears to be negative, so capturing long-term ROI from CI enterprise requires establishing the value of those science, innovation, and workforce outcomes described above.

The matrix below can be used to identify value propositions for each stakeholder group. By listing all significant stakeholder groups along the vertical axis and determining the value each desires from each category at least helps CI enterprise leaders determine where they have little strength in speaking to stakeholders. When dimensions of value are understood, it becomes possible to identify and track appropriate measures of value to better communicate value to stakeholders. Useful measures for some of these strategic dimensions are sparse at this time. We now examine creative Level 2-3 measures for the workforce column.

	Science	**Innovation**	**Workforce**	**Economic**
Stakeholder1	Potential Value Proposition	Potential Value Proposition	Potential Value Proposition	Potential Value Proposition
Stakeholder2	Potential Value Proposition	Potential Value Proposition	Potential Value Proposition	Potential Value Proposition
Stakeholder3	Potential Value Proposition	Potential Value Proposition	Potential Value Proposition	Potential Value Proposition

Figure 5: Stakeholder Value Matrix

Impacts at Levels 2 and 3: An Example of Workforce Changes

Workshop participants noted that finding and holding on to good people is a major challenge. Relevant, leading-edge skills are in great demand, and research-oriented CI enterprises that lose personnel to industry often see this as a failure in that such talent is “lost to science.” That talent must be replaced, and the difficulty and expense of expert training is daunting. However, this is only one way to think about the issue. CI enterprises contribute to the economy when key personnel depart. This “diaspora” has a beneficial side, as the emigrant diaspora from economically developing countries to developed countries shows. It is possible to view the departure of talent as a net loss to the country of origin, but this has also been found to contribute positively to developing nations by providing contacts, experience, and business for originating countries (Beine et al, 2001; Smart and Hsu, 2004, Kuznetsov, 2006). We explore this using research into nine CI enterprises.

CI enterprises demonstrate three kinds of benefits from workforce diaspora. First, people with leading edge skills can expand the capabilities of the nation’s private sector, providing both human capital and advanced technology for entrepreneurial ventures. Such people contribute to regional economic development and create an economic return for the CI enterprise through active, alumni-oriented activity. Second, skilled employees from research-oriented CI enterprises often become leaders in new or existing CI enterprises in other locations. One organization loses skills, but net capabilities can be enhanced. Third, the diaspora creates a cadre of science-trained users of CI. When a research-oriented CI enterprise loses a skilled user of a local compute cluster through a move to a national-level CI resource it adds capability and contributes to scientific activity at the most advanced levels. Similarly, skilled users trained by university-based CI enterprises might go to innovative companies that want to exploit CI capabilities, thereby possibly creating new "customers" for the CI enterprise and building national capability in the application of CI to practical product or service opportunities.

When seen from the human capital perspective, CI workforce losses can be seen as positive, enabling next-generation science in software, systems, storage, and networking. The technical dimensions are easy to see but the *human* elements are not (Lee et al 2006). The emerging occupational category of 'data scientist' has sourced a good deal of talent and knowledge from CI enterprise (Davenport and Patil, 2012). The movement of these people brought increased national capabilities, workforce development, human infrastructure development, and alumni business development. The loss of human capital to research-oriented CI enterprises creates challenges for those enterprises, but the diaspora arguably helps national competitiveness. Employees departing research-oriented CI enterprises are often replaced by young talent, thus "forcing" training across generations and opening attractive career paths via the creation of a CI enterprise alumni network.

Human capital development is important to national and international innovation systems (Bozeman et al 2001; Bozeman and Mangematin, 2004). Science and technology training helps establish new businesses (Murray, 2004; Ding and Choi, 2011). Research-oriented CI enterprise helps in this process, with impacts beyond Levels 0 or 1. Numbers of CPUs, GPUs, memory per core, memory allowed per job, etc. do not say much about workforce impact (Stack & Biefield, 2012). Some progress is being made on science impacts (publications, citations, etc.) that can help with Level 2 measures, but CI enterprise leaders need help with Level 3 measures. By reframing "loss" of talent as a contribution to regional or national capability, it is possible to turn a challenge into an important Level 3 indicator. After all, many research-oriented CI enterprises are located in educational institutions that produce talent for others all the time. Research-oriented CI enterprises that consider their ex-staffers as "alumni," noting where they go and keeping in touch with them, can gain much. Research-oriented CI enterprise can characterize departing talent increases in salary as "value added," highlight entrepreneurial enterprises founded by alums, and track the spread of advanced techniques from to industry through the migration of alums.

Smaller or newer CI enterprises that have not established diaspora effects may join together to establish the appropriate workforce measures. One CI enterprise may not be able to tell a compelling story about diaspora, but multiple CI enterprises might. Coming together around measurement could be useful for benchmarking both low level operational performance and higher level impacts.

Benchmarking and Science Executive Education

CI enterprises are in some ways *sui generis*. Other kinds of organizations are not directly comparable, and significant interpretation must accompany comparisons. Yet CI enterprises have experience as both collaborators and competitors among themselves. Competition inhibits direct sharing of details about management with other CI enterprises, and this extends to relationships with other kinds of organizations. Knowing when to be collaborative and when to be competitive is a major challenge for CI enterprise leaders. For example, should CI enterprises be competitive or collaborative with private-sector companies such as Google or Amazon? Benchmarking is difficult, making learning more difficult. This became clear in a discussion of budgets for high-performance computing hardware when “standing up” a computational resource. There was no “typical breakdown” for CI enterprises to compare with industry.

Benchmarking can facilitate organizational learning. It is practiced by many industrial organizations, often assisted by management consulting firms. It relies on a trusted third party to aggregate and summarize organizational metrics without revealing the particulars of individual enterprises that might be competitors. Benchmarking also results in match-making by brokering non-anonymous exchanges of detail in particular areas. Workshop participants recognized the possible value of benchmarking among CI enterprises and between these enterprises and industry infrastructure providers. However, a trusted third party does not yet exist, and there was doubt that results could be aggregated to protect anonymity. Still, progress is evident in the work of the Coalition of Academic Scientific Computing (CASC), which has sponsored benchmarking efforts aimed at low-level operational measures and high-level impact measures (Berente & Rubleske 2012).

Another promising step is “science executive” education aimed at CI enterprise leaders. Such leaders often learn as entrepreneurs learn, through on-the-job trial-and-error, often without exposure to the knowledge from organization science that might help them (Cummings and Keisler, 2011; Berente and Claggett, 2012). Knowledge in organizational governance, innovation management, resource provisioning, workforce development, turnover reduction, process improvement, marketing, and strategic leadership can be taught through executive education, as shown in organizational contexts other than science enterprise (Vicere, 1989; Mintzberg and Gosling, 2002; Clegg and Smith, 2003). Science executive education applies these traditions to science enterprise.

Executive education began in the late nineteenth century and expanded during World War II to facilitate wartime production, and focused on globalization (Crotty and Soule, 1997). Since 1990 it has addressed cost-cutting, business process reengineering, managing mergers and acquisitions, exploiting new partnerships and alliances, negotiation, and coping with competition and technological change (Fisher and Ury, 1981; Vicere, 1989; Ready et al., 1993; Crotty and Soule, 1997; Conger and Xin, 2000; Clegg and Smith, 2003). Executive education today focuses on transforming and revitalizing organizations, continuous innovation and the bypassing of functional silos such as accounting, marketing and finance (Mintzberg and Gosling, 2002; Pfeffer and Fong, 2002, Doh, 2003; Tushman et al., 2007). Specialized, cohort-based programs are becoming more popular than all-purpose, open admission programs. Evidence-based management built on research debunks popular but ineffective fads (Conger and Xin, 2000; Pfeffer and Fong, 2002; Tushman and O’Reilley, 2007; Tushman et al., 2007; Burke and Rau, 2010). Face-to-face learning is essential, consistent with research on scientific collaboration (Mintzberg and Gosling, 2002; Olson, et. al., 2008).

Business executive education cannot be directly applied to science executives because business focuses on industries in competitive markets with clear success criteria such as profit. Business executive education typically presumes some form of command-and-control structures with clear lines of authority. In contrast, science is competitive in ways different from business, with its own performance and success criteria that can be difficult to understand, measure, and communicate. Science organizations often have skilled researchers and world-class scientists who operate more like franchisees than employees. They often see substantive knowledge as more important than formal authority. Some have security of employment such as academic tenure. Direct application of business executive education does not fit well with science executive education.

Participants in a “birds of a feather” session at SC11 recommended that science executive education focus on matching sources and uses for funds over time, explaining the “value-added” of enterprises to various constituencies, improving hiring and retention of key employees, and better handling of the “socio” in socio-technical. The lack of science executive expertise is a “rate-limiter,” impeding CI enterprise from greater coordination and collaboration. CI enterprise leaders increasingly have to balance long-term vs. short-term goals, temporary projects vs. permanent organization; planning vs. spontaneous action; and standardization vs. fluid technical innovation (Ribes and Finholt 2009). Extending project management to entrepreneurial leadership is at the center of science executive education (Cummings and Keisler 2007; 2011; Karasti et al., 2010; Claggett and Berente 2012; Rubleske and Berente 2012).

Conclusion

The workshop explored how CI enterprises can benefit from collaborating with organization scientists. Keynote speaker Margaret Palmer, director of the Socio-Environmental Synthesis Center (SESYNC), noted two aspects of special importance to the workshop. One was the opportunity to see any particular enterprise as an experiment in organization. Scientific experiments vary conditions, measure controls, observe results, and ascribe causality. A scientific enterprise can similarly advance understanding of how to organize by measuring and adjusting. This organizational learning is reminiscent of continuous improvement and similar quality management approaches applied to a scientific audience. It presents an opportunity to draw organization science and CI enterprise closer together by viewing different enterprises as experiments in organizing.

Palmer also said SESYNC benefited in its organization and design from organization science directly. Senior staff read and learned from literature on team composition, spatial ergonomics for collaboration, interdisciplinarity and distance collaboration. During its organizational design phase SESYNC provided honoraria to key researchers in organization science so they would help design the enterprise and its processes. These researchers provided guidance, helped interpret literature to fit specific organizational goals, and assisted in choosing the organizational metrics the enterprise would measure in its on-going conceptualization of itself as an experiment in organizing for innovative, interdisciplinary science.

The workshop reinforced the results of prior workshops. There is much to gain from collaboration between organization scientists and cyberinfrastructure enterprise leaders. The benefits of this collaboration can accrue to both sides in the discussion. The objective of this workshop was to move beyond the view that collaboration is valuable to detailed discussion of what the stakeholders in this effort need and want from collaboration. These discussions are now leading to reinforcing behaviors around executive education and other potential areas of collaboration. In order for this key element of our infrastructure to deliver long-term value to society, it will be essential to build on and extend the points of collaboration among these enterprises.

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