This research study is available online at the ECAR website (www.educause.edu/ecar).
Higher Education IT and Cyberinfrastructure: Integrating Technologies for Scholarship
EDUCAUSE is a nonprofit association whose mission is to advance higher education by promoting the intelligent use of information technology.

The mission of the EDUCAUSE Center for Applied Research is to foster better decision making by conducting and disseminating research and analysis about the role and implications of information technology in higher education. ECAR will systematically address many of the challenges brought more sharply into focus by information technologies.

Copyright 2008 EDUCAUSE. All rights reserved. This ECAR research study is proprietary and intended for use only by subscribers and those who have purchased this study. Reproduction, or distribution of ECAR research studies to those not formally affiliated with the subscribing organization, is strictly prohibited unless prior written permission is granted by EDUCAUSE. Requests for permission to reprint or distribute should be sent to ecar@educause.edu.
**Contents**

**Foreword** ........................................................................................................................................... 5

**Chapter 1**  
Executive Summary ................................................................................................................................. 9  
Defining Cyberinfrastructure • Methodology • Key Findings • Conclusion

**Chapter 2**  
Introduction, Methodology, and Demographics .................................................................................. 17  
Studying Cyberinfrastructure • Research Approach • Classification Schemes • Analysis and Reporting Conventions • Overview of Respondents • Study Organization

**Chapter 3**  
Cyberinfrastructure on Campus ........................................................................................................... 27  
Utilization of Cyberinfrastructure Resources • Sources of Cyberinfrastructure Technologies • Importance of Cyberinfrastructure Technologies • Summary and Implications

**Chapter 4**  
Understanding the Cyberinfrastructure Landscape ............................................................................... 49  
CIO’s Knowledge • Cyberinfrastructure Technology Inventories • Other Executives’ Knowledge • Summary and Implications

**Chapter 5**  
Cyberinfrastructure Underpinnings: Support for Support .................................................................... 61  
Accountability • Authority and Resources • Aids to More Effective Support for CI Technologies • Summary and Implications

**Chapter 6**  
Pulling Together to Support Research ................................................................................................. 79  
Collaboration • Integrating Cyberinfrastructure Resources • Summary and Implications

**Appendix A**  
Institutional Respondents to the Online Survey .................................................................................... 97

**Appendix B**  
Interviewees in Qualitative Research ................................................................................................... 103

**Appendix C**  
Bibliography .......................................................................................................................................... 105

**Appendix D**  
Statistical Details (Selected Tables) ..................................................................................................... 107
When university researchers invented the first computers, they set in motion a process that would reinvent both universities and research. After half a century, the twin tracks of this story are individually fascinating and thoroughly intertwined. Along one track, higher education institutions followed a long and often difficult path to developing an enterprise information technology (IT) capability. Computers began to revolutionize university administration soon after they became commercial products; later took over the desktops of staff, faculty, and students alike; and eventually, fortified by network connections, became a universal platform facilitating every aspect of institutional work, from finance to instruction.

Along the other track, IT transformed research. Information technology, born in the lab, never left it. Indeed, to some extent the computer and its network became the lab. Computation, originally a way of speeding up drudge work, evolved into an entirely new way of doing science. Digitization made data spectacularly more accessible, analyzable, and (above all) abundant. And as technology underwent one order-of-magnitude performance improvement after another, researchers rushed avidly to the outer limits of IT possibility—and dreamed of what they could do with the next 10- or 100-fold advance.

It was inevitable, and in many ways desirable, that these different tracks would create separate IT cultures on campus. Once marginalized technicians, institutional IT leaders became executives and agents of strategic achievement. Often learning the hard way, central IT units developed competencies in change management, security, and policy, and it became their role to promote enterprise awareness and good IT citizenship across complex distributed IT environments. University researchers, for their part, were caught in a two-way squeeze. On one hand they yearned for IT independence. They needed super-optimized systems subject to their full control, and they competed intensely both for the research funds that paid for their systems and for the professional honors that accompany breakthrough results. They were not keen to dilute this autonomy. Yet the logic of modern scientific research led them also to collaboration and cooperation, often on an international scale. Game-changing creations like the Internet, supercomputing centers, and grid computing were partly a result of—and partly a catalyst for—this increasing interdependence. But where, exactly, did the lab and the grid meet the enterprise?

That question gained new focus when in 2003, the National Science Foundation (NSF) crystallized years of thought about IT’s
role in research and education by identifying cyberinfrastructure (CI) as an essential enabler of future scientific research. Distinguishing cyberinfrastructure both from commodity resources and from the specialized tools used in particular projects, the NSF described it as a platform “for the empowerment of specific communities of researchers to innovate and eventually revolutionize what they do.” Technologies such as high-performance computing, mass storage, advanced networks, and collaborative tools would collectively constitute, in the NSF’s vision (and in similar visions around the world often described as e-science or e-research), a sort of scientific commons where all kinds of knowledge could be exchanged, analyzed, and integrated. But the revolutionizing described in the vision extended beyond research results. Funding and governing CI demands significant changes in the cottage-industry research model of project-oriented grant funding, investigator ownership of resources, and relative lab independence. An effective cyberinfrastructure will have to be integrated deeply into the enterprise and the wider world beyond.

These changes in turn suggest a new phase in the relationship between the different IT cultures of central IT and the research units—and that’s what brought us to this study. Campus IT leaders today are keen to support institutional strategic goals, and there’s nothing more strategic for higher education than research and the educational mission it supports. Providing and supporting cyberinfrastructure is likely to take central involvement; questions of standardization, integration, scale, and funding loom large. But how much central IT involvement is enough, and what form should it take? How can IT leaders overcome the skepticism they confront when they tell researchers, “I’m from central IT, and I’m here to help”?

This study began with just such questions within the higher education IT community. In July 2007, EDUCAUSE hosted a summit of higher education leaders and others to discuss ideas about supporting research in general and cyberinfrastructure in particular. Ideas were plentiful; empirical data about how institutions used CI technologies, funded them, and supported them was not. The group recommended to EDUCAUSE Vice President Mark Luker that EDUCAUSE conduct a survey of CI practices among its member institutions. Partnering with Mark and his Net@EDU team, ECAR carried out the survey in December 2007 and January 2008, and we are now proud to present ECAR Fellow Mark Sheehan’s fine study assessing the results.

As in previous ECAR studies relating to the research mission, we found our CIO respondents deeply if selectively involved in IT support for research and concerned about improving its performance. The much-discussed fragmentation of campus CI usage and funding was apparent; for four of the five CI technologies we asked about, access was most commonly provided by researchers and their labs. Yet central IT was the second most common source for all of these technologies, and it was the primary source for the highly strategic fifth technology, advanced networking.

Given this mix of distribution and central IT involvement, and taking into account the CIO mandate to promote enterprise awareness, perhaps it’s not surprising that our respondents gave low to mediocre marks to researchers’ collaboration in the use of CI resources, to their institutions’ ability to achieve economies of scale in CI, and to the existence of incentives for researchers to pursue these goals. CIOs, however, did not present themselves as wandering in an ungovernable CI wilderness. Contrary to a common worry that research use of IT is simply too complex and atomized to be comprehended, let alone managed, our respondents generally agreed that they could find out what they needed to know, that they had knowledgeable executive colleagues, and that they had
the authority they needed to meet their CI responsibilities. What our respondents said they lacked—or rather, what they thought would help them the most—was increased funding and better communication and outreach with the research community.

On the whole, our study results provide good reason to believe that the low-grade culture war that has sometimes characterized central IT and research relationships can and will abate in a mutual recognition that different parts of campus bringing complementary skills can work together to realize the promises of cyberinfrastructure. We especially hope that this study will give higher education CIOs a sense of where and how they can make their most effective contributions to CI support and the institutional success it engenders.

For their generous assistance in developing the survey instrument on which this study is based, ECAR expresses its appreciation to the members of the project advisory committee: Rosio Alvarez, CIO, Lawrence Berkeley National Laboratory; Sally Jackson, CIO, University of Illinois, Urbana-Champaign; Kevin Morooney, Vice President for Information Technology, CIO, The Pennsylvania State University; Jim Pepin, Chief Technology Officer, Clemson University; Peter Siegel, CIO and Vice Provost, Information and Educational Technology, University of California, Davis; and Joel Smith, Vice Provost and CIO, Carnegie Mellon University. In addition, for their gracious and thoughtful participation in a review of preliminary findings, we thank Patrick J. Burns, Vice President for Information Technology, Colorado State University; Dennis M. Maloney, Chief Technology Officer, University of Colorado; Steven Senator, U.S. Air Force Academy; and Randall J. Stiles, Vice President of Information Management, Colorado College.

We are also deeply indebted to the 369 survey respondents who made this study possible; their institutions are listed in Appendix A. Qualitative interviews with the 12 IT leaders listed in Appendix B greatly enlivened and enriched our research, and we thank them for their time and insight.

Readers will quickly recognize that principal investigator and author Mark Sheehan has produced a gracefully written and meticulously analyzed study that reflects his experience as a CIO and trained scientist. Mark’s tenacity and hard work made it possible for us to respond in a timely way to our community’s request for this study. Like all ECAR publications, this one also relied on a great deal of talent and collaboration within EDUCAUSE. EDUCAUSE Vice President Mark Luker and Government Relations Officer Garret Sern provided much-appreciated leadership, encouragement, and guidance. Richard N. Katz, EDUCAUSE vice president, and ECAR Fellows Toby Sitko and Gail Salaway made many contributions to the study, from conception to final report. And as always, the EDUCAUSE publications team, led by Nancy Hays and orchestrated by our editor Gregory Dobbin, ensured that the final product met our high-quality standards. We are proud of the work of this talented team.

Ron Yanosky
Boulder, Colorado

Endnote
Executive Summary

Like the weather, everyone seems to be talking about cyberinfrastructure. Unlike the weather, everyone also seems to be doing something about it—usually something unique to their campus research environment. The term cyberinfrastructure (CI) seems to have evolved as a semantic rallying point around which to gather best practices in support of IT in research. As San Diego Supercomputer Center Director Fran Berman said, “The challenge of cyberinfrastructure is to integrate relevant and often disparate resources to provide a useful, usable, and enabling framework for research and discovery characterized by broad access and ‘end-to-end’ coordination.”

To many, those challenges send a tingle of apprehension up the spine. Research and discovery have traditionally been led by faculty in whose disciplines and at whose institutions individual achievement has been the sine qua non of recognition, promotion, and tenure—all elements of professional success. This has led to a cottage-industry approach to research on many campuses that stands in contrast—if not outright opposition—to the aims of CI: to integrate critical research technologies with an eye to encouraging and enabling collaboration among researchers, achieving economies of scale within the institution or the discipline in order to husband scarce resources, and developing a seamless fabric of research support infrastructure and services equally valuable to and equally usable by novice and expert.

Not surprisingly, best practices in CI support and integration are few. To be fair, the target is constantly in motion. Predictably, today’s supercomputers are tomorrow’s white elephants; the “massive” data storage arrays of a few years ago can be added to this year’s laptop PC for a few dollars extra, and maintaining network bandwidth sufficient for advanced scientific applications requires either buying orders of magnitude too much now or playing catch-up ever after. Until recently, CIOs looking for strategic guidance about CI have had relatively few resources to turn to and, for the most part, have had to “make it up as they go along.”

A frustration common to many CIOs is the scarcity of factual information about CI practices at other campuses. In July 2007, EDUCAUSE Vice President Mark Luker responded to a request from the Net@EDU Campus Cyberinfrastructure Working Group for EDUCAUSE to help address this need by commissioning the EDUCAUSE Center for Applied Research (ECAR) to conduct a limited study of the higher education CI landscape.
Luker worked with fellow EDUCAUSE Vice President Richard Katz and EDUCAUSE Center for Applied Research Interim Director Ron Yanosky to inaugurate the study on which this report is based.

**Defining Cyberinfrastructure**

As one of our advisers remarked, the very term *cyberinfrastructure* is part of the problem; it means everything and it means nothing. It’s not that the National Science Foundation (NSF) was unclear when it coined the term in 2001, but its subsequent usage by the higher education community has been inconsistent, sometimes broadening and sometimes restricting its original scope. As we conducted this study, we heard many times from respondents to our quantitative survey and in our qualitative interviews that the term has become a buzzword and lacks enduring meaning. Several respondents preferred the equivalent European terms *e-science* and the somewhat less restrictive *e-research*. Although various questions in our survey asked about research outside science and engineering and inquired about CI technologies used in creative activities and teaching and learning, the bulk of our findings did reflect science and engineering research use.

Specifically, our survey asked about five research–related information technologies: high-performance computing resources, CI applications and tools, data storage and management resources, advanced network infrastructure resources, and resources for collaboration within virtual communities. Chapter 3 defines each of these areas in more detail. In addition to the obvious questions about who uses, who provides, and who funds CI resources, we asked how important each technology was to various academic areas at present, and about how respondents thought their importance to research and to teaching and learning would change in three years.

We asked how much is known about each of the technologies and about their use on campus, whom the CEO holds accountable for various research-related activities, and whether the CIO has sufficient authority and resources to meet his or her responsibilities for those activities. Finally, we asked about the use of two collaborative practices, about institutional incentives to use them, and about the central IT organization’s effectiveness at integrating CI technologies to provide seamless support for research.

**Methodology**

ECAR applied a multipart research approach to this study, which involved

- a literature review to identify issues and establish the research questions;
- consultation with a select group of CI experts to identify and validate research questions;
- a quantitative web-based survey of IT administrators (mostly CIOs) responded to by 369 U.S. and Canadian higher education institutions among the EDUCAUSE member base; and
- postsurvey qualitative interviews with 12 executives and staff members involved with cyberinfrastructure resources and practices at 11 institutions.

In the introduction to our survey, we asked explicitly that the CIO complete it personally. More than three-quarters complied; the remaining respondents had various campus roles, most of them in the central IT organization. Accordingly, our results reflect a predominantly CIO point of view and should be interpreted in that light.

**Key Findings**

We found several general patterns in the data our respondents provided. Research institutions told us their researchers make more use of CI technologies than do teaching institutions. Respondents tended to rate their overall knowledge of CI technologies
high but their resources for meeting their research-related responsibilities low. They rated research-related collaborative practices at their institutions low, and their own organizations’ effectiveness at integrating CI technologies even lower. Nevertheless, a look at the specifics gives some reason to hope that the vision of an institutional research enterprise is achievable, and it at least tentatively suggests some steps that institutions might take to help make that happen.

Use of CI Technologies

As Figure 1-1 shows, institutions that self-identified as having a research-focused mission predominantly report that their researchers use all five CI technologies; researchers at institutions with a teaching mission are much more likely to use only a few of them.

About two-thirds of respondents reported at least some research use of CI applications and tools, data storage and management resources, and resources for collaboration within virtual communities. By contrast, just under half are making any use of high-performance computing resources or advanced network infrastructure resources for research, perhaps because of the relatively high cost or the complexity of these technologies.

Researchers obtain access to most CI technologies mainly through the use of their own resources or those of their labs, reinforcing the perception that research IT resources are highly distributed. Central IT is the next most frequently used source for these technologies, but at most institutions it is the primary source of advanced network infrastructure. With the exception of resources for collaboration within virtual communities, most institutions rate CI technologies as being most important to research in science and engineering and of substantially less importance in other academic areas. Institutional mission most often determines where the importance of CI technologies will change the most. Research institutions anticipate a greater increase in importance to research than to teaching activities, and teaching institutions report the opposite; the level of anticipated increase in importance of all technologies to both types of activity is greater at research institutions.
Knowledge about CI Technologies

Following on—and no doubt related to—our finding that central IT is the primary source of advanced network infrastructure resources, CIOs tell us that this is the CI technology about which, on average, they know the most. This echoes a broader trend that emerges from our data: the CIOs reported that knowledge about a technology increases with the extent to which central IT provides access to and funding for it. When we asked for details about the CIO’s CI-technology savvy, we learned that they know the most about which CI resources are available to researchers, who provides them, and who funds them; they know less about who is using them and what they are used for.

Respondents generally rate their ability to obtain information about CI technology use as good or better. Their assessment of their ability to obtain information is positively associated with the level of knowledge they say they have, though mean ability to know about a given technology is always rated higher than actual knowledge. The extent of that knowledge, in turn, is positively associated with the five indicators of progress toward an enterprise model of research support, as discussed in Chapter 6. This suggests that a campus environment in which information about the use of CI technologies is openly shared between researcher and central IT is important to achieving the full potential of cyberinfrastructure.

Inventories of CI technology resources are common, but complete inventories are rare, exceeding 20% of cases only for high-performance computing resources and advanced network infrastructure resources. The completeness of the inventory for each technology is positively associated with the CIO’s reported level of knowledge about it.

The CIO isn’t always the most knowledgeable official about a given technology. As Figure 1-2 illustrates, respondents on average rate the CIO’s knowledge about high-performance computing and CI applications and tools below that of the chief research officer and science and engineering deans; for the other three technologies, respondents rate the CIO’s knowledge level higher than that of the four other executives.

Enabling an Enterprise Approach

The central IT organization’s success depends on numerous factors, many of which rely on the organization’s own efforts. Still, in several important ways the campus can help central IT succeed in its role of coordinating CI support. We asked about three factors that devolve upon central IT largely from external sources: accountability, authority, and resources. We posed our questions in the context of eight research-related activities.

Service activities:
- support services for research IT systems
- security for research systems
- ongoing maintenance and support for IT resources obtained with one-time research funds
- enforcement of national privacy regulations

Infrastructure activities:
- network bandwidth for research
- network bandwidth for teaching and learning
- storage for research data
- space and environmental support for research IT resources owned by campus entities other than central IT

For all of these activities, the CIO is the officer most often named as the one held accountable by the CEO. Respondents most frequently tell us that other officers are accountable for the enforcement of privacy regulations and for providing space
and environmental support for non-central IT resources; the chief academic officer is named second most frequently in the former case and academic deans in the latter.

Within this context of extensive CIO accountability, our respondents seemed less concerned about a lack of authority than a lack of resources. Their mean level of agreement that CIOs have sufficient authority to meet their responsibilities is well above neutral for all activities except ongoing maintenance and support for resources obtained with one-time funds, enforcement of privacy regulations, and providing space and environmental support for non-central IT resources. For these activities, agreement is closer to neutral. In all cases, agreement that the CIO has sufficient resources to meet responsibilities for these activities is substantially lower. The greatest difference between reported sufficiency of authority and resources was for providing storage space for research data. (Data storage and management is also the CI technology whose importance to both research and teaching and learning respondents predicted would increase the most in the next three years.)

In another section of our survey, respondents told us that for all five CI technologies, more funding for central IT infrastructure and services would help them support more effective research use at their institutions. This seems consistent with the shortfall in sufficiency of resources relative to authority reported for the eight research-related activities. The needs for data storage and management resources, advanced network infrastructure resources, and resources for collaboration within virtual communities appeared to be greatest. Respondents also identified better communication and outreach between researchers and central IT as something that would improve their support for research. Substantial numbers identified a greater role for central IT in developing budgets for the institution’s research grants and contracts as one possible mechanism for improving the supply of funding for central IT’s support of...
research. Relatively few respondents cited increased authority to enforce standards for the acquisition and management of research resources as potentially benefiting central IT’s support for research.

Finding Synergies

One of the goals of cyberinfrastructure is to create a research IT environment that is rich in resources and support services that are highly available when and where they are needed. As we have seen, central IT has a role in providing and funding such resources and services, but the universe of need and the pace of technological change are well beyond the capacities of even the best-funded central IT organization. Achieving economies of scale in the use of specialized research IT resources relies in part on researchers themselves offering some of the capacity of those resources to their colleagues under a variety of collaborative scenarios, and it relies on them as well to work with central IT where appropriate to ensure optimal management of shared or shareable resources.

As Table 1-1 shows, our respondents, on average, gave their institutions’ researchers mediocre scores for collaboration and gave their institutions somewhat poorer scores for achieving economies of scale and for providing incentives to collaborative behavior.

Of course these mean findings comprise a mix of higher and lower scores, and if we break the respondent population down along certain lines, we see that some institutions are doing better than others. For example, we found respondents more positive about collaborative practices and incentives to collaborate at institutions where central IT provides and funds various combinations of CI technologies, where the CIO is knowledgeable about them, and where inventories of CI resources are more complete. We found a similar effect where CIOs have sufficient authority and resources to meet their responsibilities for providing a variety of support services as well as space and environmental support for CI technologies.

The integration of advanced IT resources into a seamless fabric of support for the research enterprise is both an overarching goal of CI and a very tall order. The factors mentioned in the previous paragraph also distinguish institutions that said they are doing well with the integration of CI resources from those that said they are not. In addition, we found that institutions whose ratings for collaborative practices and institutional incentives were higher also said they did better at integrating CI resources. Figure 1-3 shows differences of about a full point on our five-point scale between those who agreed or strongly agreed about the four items and those who disagreed or strongly disagreed.

Conclusion

We don’t perceive that the aim of “the cyberinfrastructure movement,” if such a thing exists, is to revolutionize the provision of research IT infrastructure and support by consolidating it in the hands of central IT. Rather, the current focus on CI seems to result from recognition that the cottage-industry model of research IT deployment in place at many institutions is inefficient, that this inefficiency may inflate the costs of research, and that there are things central IT can do, in partnership with researchers, to lower costs without compromising research quality. One of the arguments for a “research enterprise” model of CI technology deployment is that the resulting synergies among researchers and between researchers and the central IT organization can improve research quality and more rapidly advance the frontiers of knowledge.

The Pennsylvania State University is a leader in cyberinfrastructure support and was cited as an example by several of our qualitative interviewees. Kevin Morooney, vice provost for information technology and CIO at Penn State, says that the high-performance
computing environment there, in particular, has “earned its consolidation. It wasn’t done either by budget or mandate, but rather by a business model and a value proposition that we constantly rework to make it attractive to do the ‘right thing.’ That is, leveraging each other’s local investments to make a consortial institutional investment that is greater than the sum of its parts.”

The data our respondents provided suggest that efficiencies like these and others are now being gained at institutions where a cluster of practices is in place. At most of these institutions, central IT plays a significant role in providing and funding each of the five CI technologies and has an internal unit dedicated to research support. The CIOs at these institutions are most often the officers who are held accountable for certain service and infrastructure activities, and they are relatively knowledgeable about research uses of the technologies. Their institutions have more nearly complete inventories of CI technologies, as well.

Table 1-1. Agreement with Statements about Collaborative Practices and Institutional Incentives

<table>
<thead>
<tr>
<th>Statement</th>
<th>N</th>
<th>Mean Agreement*</th>
<th>Std. Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Researchers generally collaborate in the use of CI resources.</td>
<td>304</td>
<td>3.03</td>
<td>0.947</td>
</tr>
<tr>
<td>Institution realizes economies of scale in the use of CI resources.</td>
<td>306</td>
<td>2.78</td>
<td>0.978</td>
</tr>
<tr>
<td>Incentives exist for researchers to share CI resources with other campus researchers.</td>
<td>310</td>
<td>2.69</td>
<td>1.011</td>
</tr>
<tr>
<td>Incentives exist for researchers to partner with central IT for economies of scale.</td>
<td>326</td>
<td>2.93</td>
<td>1.092</td>
</tr>
</tbody>
</table>

*Scale: 1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, 5 = strongly agree

Figure 1-3. Effectiveness at Integrating CI Resources, by Agreement about Collaborative Practices and Incentives

*Scale: 1 = not effective, 2 = slightly effective, 3 = moderately effective, 4 = very effective, 5 = extremely effective
In its studies, ECAR often finds that funding for IT infrastructure and services in higher education is inadequate, and the research support area is no exception. Nevertheless, where we see positive progress toward an integrated CI technology environment, we also see stronger agreement that the resources the CIO has for meeting responsibilities related to research support are sufficient. The CIO’s reported authority to meet those responsibilities follows the same pattern, and we interpret these two findings as indicating a level of empowerment of central IT by the institution’s administration and governance bodies. Along these lines, where a research-specific IT governance/advisory body existed, respondents reported that central IT’s integration of CI resources was more effective. Finally, an atmosphere of collaboration, resource sharing, and the active pursuit of economies of scale are all associated with more effective integration of CI resources.

In our study, the number of institutions that reported doing a good job at integrating CI resources was relatively low. It would appear that progress in that direction, fueled by the efficiency-related interests of the major research funding agencies and higher education institutions themselves, is still gaining momentum. Nevertheless, we believe the evidence from this study supports the vision of an enterprise-level cyberinfrastructure and hope it provides some hints, at least, as to efforts central IT can make—and can engage the institution in—that will lead toward excellence in the support of research.

Endnotes
Cyberinfrastructure (CI) is not a term that trips lightly off the tongue or one that reveals its precise meaning without some coaxing. Although its coinage is credited in a 2001 publication\(^1\) to Ruzena Bajscy, then NSF Associate Director for Computer and Information Science and Engineering, its first wide exposure was in the 2003 report of a blue-ribbon panel advising the NSF. The panel’s report explained cyberinfrastructure as follows:

The term *infrastructure* has been used since the 1920s to refer collectively to the roads, power grids, telephone systems, bridges, rail lines, and similar public works that are required for an industrial economy to function. Although good infrastructure is often taken for granted and noticed only when it stops functioning, it is among the most complex and expensive things that society creates. The newer term *cyberinfrastructure* refers to infrastructure based upon distributed computer, information, and communication technology. If *infrastructure* is required for an *industrial* economy, then we could say that *cyberinfrastructure* is required for a *knowledge* economy.... The base technologies underlying cyberinfrastructure are the integrated electro-optical components of computation, storage, and communication that continue to advance in raw capacity at exponential rates. Above the cyberinfrastructure layer are software programs, services, instruments, data, information, knowledge, and social practices applicable to specific projects, disciplines, and communities of practice. Between these two layers is the *cyberinfrastructure* layer of enabling hardware, algorithms, software, communications, institutions, and personnel. This layer should provide an effective and efficient platform for the empowerment of specific communities of researchers to innovate and eventually revolutionize what they do, how they do it, and who participates.\(^2\)

**Studying Cyberinfrastructure**

Even though this NSF report defined CI specifically in the context of research in science and engineering, the definition quoted above was endorsed by scholars in the humanities and social sciences as well, in a report published in 2006 by the American Council of
Learned Societies. Various publications also speak to its adoption by the research-library and teaching-and-learning communities. The University of California at San Diego, always a leader in cyberinfrastructure applications, hosted a 2006 summer workshop for cyber-infrastructure in the humanities, arts, and social sciences.

Despite the clarity of the concept of CI provided by NSF’s definition, many practitioners find it more ambiguous when it comes time to put CI into place or to support it. For CIOs, the dividing line between IT infrastructure for advanced research and scholarship, and infrastructure for everyday computing is blurred by variability in the researchers’ level of need; by the rapid progress of technology, in which today’s supercomputer is tomorrow’s white elephant; and by higher education’s pervasive decentralized, researcher-centric, cottage-industry style of funding, outfitting, and supporting advanced research.

For these reasons, especially the last, it is often a struggle for CIOs to establish an enterprise-wide foundation for CI, a foundation that reaps the advantages of both centralized and decentralized CI resources. CIOs can—and most do—acquire and make available research resources whose acquisition and life-cycle costs are beyond the means of most individual researchers. Advanced network infrastructure resources emerge in this study as the best example. But researcher-owned and -operated IT resources usually play a crucial role, if not a central one, in an institution’s research activity, as do remote resources available to campus researchers through consortia, government agencies, and private industry.

For a range of good reasons and from a variety of directions, today’s CIO is pressed to coordinate acquisition of or access to research resources, connect them optimally to campus networks and beyond, facilitate their sharing on campus and off, and—most difficult—integrate them into a seamless fabric of technologies that is within reach of the novice yet is indispensable to the expert. This ECAR study aims to document the patterns of use of CI resources in higher education, along with leadership knowledge about CI, to assess the status of integration and collaborative use of those resources and to identify potential ways in which IT leaders can help institutions enhance the use of CI resources.

Over the course of two days, July 10–11, 2007, a group of higher education CIOs and other interested parties met in Denver to address these issues at the EDUCAUSE Cyberinfrastructure Summit. Starting from a broad, context-setting discussion of support strategies for the higher education research mission, the discussion diverged into five distinct topics:

- The leadership role the central IT organization must play in strategic planning for robust CI on campus
- Setting priorities and finding funding for often unanticipated campus CI initiatives
- Long-term strategies for developing an institutional culture in which sharing of CI resources becomes a corollary to acquiring them
- Short-term strategies for achieving consensus in the face of competing approaches to CI resource acquisition, management, and support
- Ways in which EDUCAUSE can leverage its resources and its connections to assist the higher education community in finding its way through the CI labyrinth

A frustration common to many of the participants was the dearth of factual information about “who is doing what” in the way of support for campus CI, accompanied by a desire to know what might be learned from better data about improving CI management. A recommendation emerged that the EDUCAUSE Center for Applied
Research (ECAR) conduct a short study of CI resources and practices among the EDUCAUSE membership. EDUCAUSE Vice President Mark Luker accepted that recommendation and worked with fellow Vice President Richard Katz and ECAR Interim Director Ron Yanosky to make it a reality.

In pursuit of “who’s doing what,” our survey asked specific questions about what are sometimes referred to as “the five pillars of cyberinfrastructure”: high-performance computing resources, CI applications and tools, data storage and management resources, advanced network infrastructure resources, and resources for collaboration within virtual communities. Chapter 3 defines each of these technologies in more detail.

To provide context for this information about CI practice, we felt it necessary to assess how much respondents feel they and other key officers know about the use and sourcing of institutional CI resources. A concern voiced at the 2007 EDUCAUSE summit (and heard often in other conversations on the topic) is that the cottage-industry model of science funding, combined with organizational decentralization, makes it difficult for campus IT leaders to assemble a thorough and accurate picture of CI use. The question of “knowability” has a bearing on both our interpretation of study results and the actions that IT leaders might reasonably take to improve institutional CI performance.

Our survey also addressed the overarching issues of accountability for a representative set of CI activities, the sufficiency of the authority and the resources CIOs have for meeting their responsibilities for those activities, the climate of collaboration existing among researchers on campus with regard to CI resources, and the central IT organization’s overall success at integrating CI resources to provide seamless support for research. We used these outcomes measures to craft suggestions about how IT leaders might address the challenges of managing CI resources and the relationships embedded in them.

Research Approach

Our research proceeded along three major pathways: a literature review, a quantitative web-based survey of IT leaders at higher education institutions among the EDUCAUSE member base, and qualitative interviews with IT executives and other staff from selected institutions.

The literature review helped identify and clarify issues, suggest hypotheses for testing, and provide supportive secondary evidence. Besides examining articles and studies from journalistic, academic, and IT practitioner sources, we relied heavily on publications from the NSF, in particular the reports of its Blue-Ribbon Advisory Panel on Cyberinfrastructure (2003) and its Cyberinfrastructure Council (2007).

With input from a steering committee assembled by Mark Luker, the members of the EDUCAUSE Research Mission Support Constituent Group attending the 2007 EDUCAUSE Annual Conference in Seattle, and the members of the EDUCAUSE Net@EDU Campus Cyberinfrastructure Working Group, the ECAR research team designed the web-based survey for senior-most IT administrators. In late November 2007, we sent invitations for the survey to 1,688 EDUCAUSE member institutions in the United States and Canada, and received 369 qualified responses (a 21.9% response rate). Appendix A lists respondents to the survey. The survey instrument itself can be found at http://www.educause.edu/SurveyInstruments/1004.

Simultaneously with our survey of U.S. and Canadian institutions, we surveyed populations of higher education institutions in Europe, Australia, and New Zealand. Results of that survey will be published in a separate ECAR research report.

ECAR used qualitative interviews to gain deeper insights into findings from the quantitative analysis and to capture ideas and viewpoints we might otherwise have missed. We interviewed 12 individuals...
involved with CI practices and resources at 11 U.S. and Canadian institutions, including higher education CIOs and others. (Appendix B lists the interviewees.) We conducted most interviews by telephone.

**Classification Schemes**

For comparison, we grouped institutions using categories derived from the 2000 edition of *The Carnegie Classification of Institutions of Higher Education*, developed by the Carnegie Foundation for the Advancement of Teaching. To obtain adequate numbers for statistical and descriptive purposes, we collapsed the Carnegie 2000 classifications as follows:

- Doctoral (DR) institutions group the doctoral-extensive and doctoral-intensive universities together.
- Master’s (MA) institutions group master's colleges and universities I and II together.
- Baccalaureate (BA) institutions combine the three Carnegie 2000 baccalaureate groups.
- Associate’s (AA) institutions are the same as the Carnegie 2000 associate's category.
- Other Carnegie institutions include specialized institutions and U.S. higher education offices.
- Canadian institutions are tracked in a separate, single category.

In November 2005, the Carnegie Foundation for the Advancement of Teaching introduced a new classification scheme employing additional institutional characteristics. We have not provided a crosswalk to the new scheme, largely because we suspect that our readers, at least in the near term, will be more familiar with the older, 2000 taxonomy.

**Analysis and Reporting Conventions**

We adhered to the following conventions in analyzing the data and reporting the results:

- Some tables and figures presented in this study have fewer than 369 respondents and have been adjusted for missing information.
- Percentages in some charts and tables may not add up to 100.0% due to rounding.
- We analyzed the data for each online survey question for differences in response patterns among Carnegie classes, private and public institutions, and institutions of varying size. Institution size is determined by the number of full-time equivalent (FTE) enrollments. We also looked for associations between other combinations of variables as appropriate. We noted differences that were both meaningful and statistically significant in the text and/or the supporting figures and tables. Note that a statistically significant relationship between variables does not necessarily indicate a causal relationship.
- When needed, the Likert scales used in the online survey are footnoted in the tables and figures that show results for those survey questions.
- Many of the questions in our survey referred to the “senior-most IT leader.” Our shorthand for that role throughout this report is “CIO,” or chief information officer. While we think this is a logical substitution in the general case, and it is a much more recognizable acronym than SMITL, we want readers to be aware that the wording of our survey questions was somewhat broader.

**Overview of Respondents**

We distributed the Cyberinfrastructure Resources and Practices survey to the EDUCAUSE institutional representative at each member institution; in most cases this was the CIO. The survey introduction specified that it should be completed by the senior-most IT administrator at the institution.
Demographics
Of the 369 respondents, 352 were from the United States or its territories and 17 were from Canada. Figure 2-1 compares the distribution of survey responses, using the Carnegie class categories described above, alongside EDUCAUSE membership and overall population size in each category. The responding schools mirror the EDUCAUSE membership much more closely than they do the overall population by Carnegie class. Proportionately, we had the strongest participation from doctoral institutions (27.1% of respondents).

The median FTE student enrollment of our survey institutions was 4,391, whereas the mean, reflecting the weight of the largest responding institutions, was 8,314. Overall, however, smaller institutions made up the bulk of this survey’s respondent base. Figure 2-2 shows the distribution of respondents by student enrollment. Institutions of 4,000 or fewer students accounted for 44.5% of respondents, those of more than 15,000 accounted for 18.3%, and those in between made up 37.2%.

Among respondent institutions, 57.9% were publicly controlled and 42.1% were under private control. Control was strongly associated with FTE enrollments and was more commonly public as enrollments increased.

Our survey was completed mainly by respondents holding the title of CIO or equivalent (77.0%), with other IT administrators and managers making up most of the remainder (see Figure 2-3). With at most 5.3% of respondents representing non-IT positions, we emphasize that the survey results reflect a CIO and IT management point of view.

Institutional Mission
Demographics
As with ECAR’s 2006 research study IT Engagement in Research: A Baseline Study,10 we found as we analyzed the data from the present study that institutional mission proved a more powerful explanatory variable than Carnegie class. Of the four missions described in Table 2-1, a majority (62.0%) selected Teaching Favored and Teaching Essential, the two most teaching-intensive categories. The remainder selected the Balanced and Research Essential categories, in which teaching plays a moderate or a small role in determining faculty and institutional success.

As Figure 2-4 shows, Research Essential and Balanced missions are the most common at doctoral institutions. No master’s, bachelor’s, or
associate’s institution reported having a Research Essential mission, although respondents at 10–20% of the bachelor’s and master’s institutions characterized their missions as Balanced. The Teaching Favored and Teaching Essential missions predominate at master’s and bachelor’s institutions. The Teaching Essential mission is overwhelmingly predominant at associate’s institutions. The “Other” category, because it comprises a wide variety of specialty and professional institutions, shows a mix of missions; they are weighted toward teaching. Canadian institutions, because they are unsorted by an equivalent to the Carnegie classes, show the most even distribution of missions, with a weighting toward research.
For this study, we found it useful to combine the categories Research Essential and Balanced into a single category that we called “research,” and to combine the categories Teaching Favored and Teaching Essential into a category we called “teaching.” These categories avoid the blending of missions that takes place in the 2000 Carnegie classification, allowing us to combine responses from research-focused master’s and bachelor’s institutions with those from the bulk of the doctoral institutions, for example, while combining teaching-focused doctorals with similarly focused master’s and bachelor’s institutions.

**Table 2-1. Categories of Institutional Mission**

<table>
<thead>
<tr>
<th>Category</th>
<th>Mission</th>
<th>Percentage of Institutions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Research Essential</td>
<td>Research and teaching are the primary missions, but research is what really drives faculty and institutional success.</td>
<td>14.7%</td>
</tr>
<tr>
<td>Balanced</td>
<td>Research and teaching are both primary missions, and they are equally important for faculty and institutional success.</td>
<td>23.4%</td>
</tr>
<tr>
<td>Teaching Favored</td>
<td>Teaching is the primary mission, but faculty research is rewarded.</td>
<td>27.2%</td>
</tr>
<tr>
<td>Teaching Essential</td>
<td>Teaching is the primary mission, and faculty research does not factor heavily in faculty and institutional success.</td>
<td>34.8%</td>
</tr>
</tbody>
</table>

**Figure 2-4. Institutional Mission, by Carnegie Class**

For the study, institutions that characterized their missions as research-focused were more likely than teaching-focused institutions to report having an officially designated office of research. As Figure 2-5 shows, it was also substantially more common for institutions with research missions to report having a governance/advisory body that deals primarily with IT issues related to research and a distinct unit within the central IT organization whose explicit mission is to support faculty, clinicians, or other researchers with their research needs.
We also asked if respondents had governance/advisory boards in place that dealt primarily with IT issues related to teaching and learning. Among institutions with research missions, 73.4% had such a governance body; at institutions with teaching missions, 74.1% had them. This difference is neither statistically significant nor particularly surprising. Although the decision to focus on research is a strategic choice a higher education institution can make, teaching and learning underlie the missions of all such institutions; therefore, the governance of IT in teaching and learning is as important to a research institution as to one that focuses on instruction.

**Study Organization**

The remainder of this report presents our findings and investigates the factors that we found to be associated with success in supporting CI technologies.

Chapter 3 reports our findings about who is doing what with the five core technologies embraced by the term cyberinfrastructure. It looks at levels of use, means of obtaining access, and sources of funding for the five technologies; the current importance of those technologies to four academic areas; and the changes our respondents anticipate for overall importance of each technology.

In Chapter 4, we assess the state of knowledge of CI technologies among our respondent institutions’ senior-most IT leaders and among a selection of other campus officers. To supplement respondents’ evaluation of the CIO’s knowledge, we introduce data describing the CIO’s ability to obtain information about the CI technologies and the status of the institutions’ inventories of resources related to each of them.

Chapter 5 includes findings related to accountability for CI service and infrastructure activities, along with data about the sufficiency of the authority and resources the CIO has to meet responsibilities related to those activities. The chapter ends with a discussion of several potentially helpful items we thought might be on the CI-support wish lists of our respondents.

Chapter 6 discusses our findings about collaborative practices related to the research use of CI resources and the effectiveness of institutional incentives to coordinate the use
of those resources in pursuit of the common good. It ends with a discussion of respondent institutions’ effectiveness at integrating CI resources to provide seamless support for research, and some of the conditions and practices associated with success.

For a summary and synthetic overview of the study findings and recommendations, see the executive summary in Chapter 1.

Endnotes
7. Atkins et al., Revolutionizing Science and Engineering.
3
Cyberinfrastructure on Campus

Progress lies not in enhancing what is, but in advancing toward what will be.
—Kahlil Gibran

Key Findings

♦ About two-thirds of respondents use three of the five core cyberinfrastructure (CI) technologies: CI applications and tools, data storage and management resources, and resources for collaboration within virtual communities; only about half use high-performance computing resources and advanced network infrastructure resources.
♦ At research institutions, CI technologies are used more frequently, and by more personnel, than at teaching institutions.
♦ CI technologies are available to researchers from a variety of providers and funders, but most researchers rely on their own resources or those of the central IT organization. Central IT also plays an important role in funding CI technologies, most notably for advanced network infrastructure resources.
♦ Most CI technologies are of substantially greater importance to research in science and engineering disciplines than to other academic areas. The exception is resources for collaboration within virtual communities, where importance is moderate for all areas.
♦ In aggregate, institutions of both types—research and teaching—foresee substantial growth in the importance of all CI technologies to both their research activities and their teaching and learning activities. Research institutions anticipate the greatest increase will occur in research use, whereas teaching institutions anticipate the greatest increase will be in teaching and learning.

The consensus of our advisers, as we prepared our survey of CI resources and practices, was that five sets of technologies lie at the core of campus CI: high-performance computing resources, CI applications and tools, data storage and management resources, advanced network infrastructure resources, and resources for collaboration within virtual communities. We devoted a section of the survey to each of these and asked essentially identical questions in each section.

To help ensure comparable responses from the diverse institutions we surveyed, we provided in our survey instrument the following definitions for the technologies:
Higher performance computing resources: Supercomputers and clusters of computers or other computational devices integrated in such a way as to provide supercomputer-like performance to individual applications. Note: The network infrastructure on which high-performance computing relies was addressed under the heading “advanced network infrastructure resources,” and we advised respondents not to consider it in answering questions about high-performance computing.

Cyberinfrastructure applications and tools: General cyberinfrastructure/e-science/e-research applications and tools that support research but are not specific to a particular discipline. These include software for simulation, parallelization, visualization, job scheduling, data mining, statistical analysis, and so forth, but not [for] specific sequencing, chemical analysis, or other disciplinary applications.

Data storage and management resources: Large-scale research data storage systems for real-time use and for archival purposes, as well as facilities, software, and procedures for periodic backup of research data sets.

Advanced network infrastructure resources: The institution’s high-performance networks on campus and [their] connections to off-campus high-performance networks that support such capabilities as massive data transfers to and from clusters, real-time visualization, and use of remote instrumentation. Off-campus networks used for advanced network infrastructure include regional or university consortial networks and such networks as Internet2 and National LambdaRail in the United States and CANARIE, AARNET, DFN, JANET, SURFnet, and others outside the United States.

Resources for collaboration within virtual communities: Facilities and support for teleconferencing, for hosting collaborations with off-campus researchers, and for the operation of remotely located research instrumentation and related devices; support for identity management and associated middleware in collaborative research activities.

This chapter reviews and discusses our findings related to campus use of all five technologies, the sources researchers turn to for accessing them, the sources that fund them, their importance to four academic areas, and their anticipated future importance to research in general and to teaching and learning.

Utilization of Cyberinfrastructure Resources

For each of our five core CI technologies, we asked responding institutions to characterize their institution’s level of research use by selecting one of the following responses: not used, used occasionally by a few personnel, used occasionally by many personnel, used often by a few personnel, and used often by many personnel. Respondents selecting the “not used” level skipped the questions about current use and importance of that technology but, like all other respondents, did have the opportunity to tell us how they thought the technology’s overall importance to research and to teaching and learning would change during the next three years.

Number of Technologies Used

Figure 3-1 shows the dramatic difference in the number of CI technologies in use (regardless of how extensively they are used) between institutions whose mission is research focused and those whose mission is focused on teaching. An overwhelming majority of research institutions report at least some use of all five CI technologies; the remainder reported using from one to four of them. No research institution reported total
abstention. The mean number of technologies in use at research institutions is 4.66 out of 5 (std. deviation 0.870) and the median is 5.

Among teaching institutions, on the other hand, 3 in 10 reported the use of no CI technologies. Between 10% and 20% reported use of one, two, three, or four of them, and only 8.8% reported using all five. The mean number of technologies in use at teaching institutions is 1.90 out of 5 (std. deviation 1.966) and the median is 2.

These findings suggest that research institutions see CI technologies as a package of tools that work together in support of the research mission. Teaching institutions, on the other hand, appear much more opportunistic in their use of CI technologies, selecting the ones that suit particular needs and not troubling with the rest.

Among teaching institutions that said they used only one CI technology, the one most frequently used was CI applications and tools; advanced network infrastructure resources and high-performance computing resources were used least often.

The number of CI technologies used was significantly associated with the presence of a distinct unit within the central IT organization whose explicit mission was to support faculty, clinicians, or other researchers with their research needs. Where all five CI technologies were in use, 43.0% of respondents reported the presence of such a unit; where one to four were in use, only 16.8% of respondents did. We speculate that this reflects central IT’s response to a higher level of demand where all CI technologies were used, though it may also be a function of how research institutions are organized, given that such institutions make up most of the population that uses all five technologies.

**Extent of Use**

Figure 3-2 presents an overview of our findings about the level of use of each of these technologies among our respondent institutions. Scant majorities said they didn’t use...
high-performance computing resources and advanced network infrastructure resources at all; non-use of the other technologies hovered between 30% and 40%. At the opposite end of the spectrum, use “often by many personnel” exceeded 12% for only one technology, data storage and management resources; values for the other technologies ranged from 5% to 12%.

In the five detailed discussions that follow, differences in usage between research and teaching institutions are most obvious in the cases of high-performance computing resources and advanced network infrastructure resources, which are not used at all at three-quarters of respondent teaching institutions. For high-performance computing resources, CI applications and tools, and data storage and management resources, patterns of usage for research institutions are fairly consistent, with percentages for use “often by a few personnel” between 40% and 50% and percentages for use “often by many personnel” between 20% and 30%. At research institutions, findings for advanced network infrastructure resources and resources for collaboration within virtual communities show patterns of substantially less pervasive use than the findings for other technologies.

High-Performance Computing Resources

In its Cyberinfrastructure Vision for 21st Century Discovery, the NSF acknowledges the crucial role played by high-performance computing in the development of a national cyberinfrastructure and asserts a five-year goal of “enabling petascale science and engineering through the deployment and support of a world-class high-performance computing environment….” At many of the institutions we surveyed, the current generation of high-performance computers is commercial supercomputers and clusters of lower-capacity devices that deliver performance comparable to that of a supercomputer.

As Figure 3-3 indicates, researchers at slightly more than three-quarters of respondent teaching institutions made no use of high-performance computing resources. Fewer than a fifth of teaching institutions reported high-performance computing use as occurring occasionally by a few personnel, and only 1 in 20 reported use often by a few personnel. By contrast, almost half of research institutions reported use often by a few personnel, and nearly another quarter reported use often by many personnel. Of
the other four technologies, only the use of data storage and management resources equaled these levels.

**Cyberinfrastructure Applications and Tools**

High-performance computers imply the existence of operating-system and application software that make efficient use of massively parallel multiprocessor computing platforms. Beyond the generation of vast numerical data sets, software for high-performance computing systems must facilitate the transformation of such mountains of data into useful information by using modeling, simulation, and visualization techniques. In its *Cyberinfrastructure Vision* document, the NSF includes the development and maintenance of supporting software as an integral component of its goal for high-performance computing, arguing that “Sophisticated software, visualization tools, middleware and scientific applications created and used by interdisciplinary teams are critical to turning flops, bytes and bits into scientific breakthroughs.”

Our respondents from teaching institutions reported substantially more occasional use of cyberinfrastructure applications and tools than of high-performance computing resources (see Figure 3-4). Just over 50% of teaching institutions reported at least some use of CI applications and tools among their researchers.

Compared with high-performance computing usage, research institutions reported slightly lower usage levels for CI applications and tools in the “often” categories and higher levels in the “occasional” categories. Consistent with this were reports by only 2.1% of research institution respondents that CI applications and tools were not used at all. (The corresponding finding for high-performance computing was 9.3%.) Although use of CI applications and tools seems to be slightly less intensive at research institutions than high-performance computing use (less use “often”), it is considerably more pervasive (more occasional use). This implies at least the occasional use of CI applications and tools on lower-performance computing platforms. Ilee Rhimes, CIO and vice provost for information technology services at the University of Southern California, confirms this interpretation. “At our institution,” he says, “visualization in particular tends to be done on specialized systems that are
powerful enough in their own right, but don’t really fit the profile of high-performance systems.”

Data Storage and Management Resources

About data, the NSF observes in Cyberinfrastructure Vision that “The enormous growth in the availability and utility of scientific data is increasing scholarly research productivity, accelerating the transformation of research outcomes into products and services, and enhancing the effectiveness of learning across the spectrum of human endeavor.”

The enormous quantities of high-value data generated by CI-based experimentation, observation, and simulation suggest that storage space and tools to manage large data sets are a critical part of the CI environment.

The usage pattern for data storage and management resources reported by our respondent institutions (see Figure 3-5) is very similar to that for CI applications and tools. Usage of data storage and management resources seems to be more pervasive than for high-performance computing resources, suggesting that as with CI applications and tools, resources for data storage and management in research are often coupled to computing platforms that our respondents did not characterize as high-performance platforms, given our definition of that technology.

Advanced Network Infrastructure Resources

While an Acrobat Reader search of the NSF’s Cyberinfrastructure Vision document turns up more than 100 occurrences of the word network (with various suffixes), only a very few refer directly to the broadband network “data pipes” that many CIOs consider to be a dominant component of CI. The NSF document refers to networks of sensors and to networked resources, data, environments, and communities, but in its vision of the future, data pipes are assumed to be in place and of sufficient capacity and flexibility to support advanced research. At least in the context of CI, NSF has clearly moved beyond its turn-of-the-century, very high speed Backbone Network Service (vBNS) program, in which it took
funding responsibility for advanced network infrastructure in support of meritorious research programs. Many research universities owe their initial Internet2 connections to vBNS grants.

Our findings (see Figure 3-6) indicate that advanced network infrastructure resources are nearly as little used at teaching institutions as high-performance computing resources are, with almost three-quarters of respondents saying their researchers do not use advanced network infrastructure resources.

Overall, research institutions report a more even distribution of usage levels for advanced network infrastructure resources than for any other CI technology. A surprisingly high number (12.1%) report non-use of advanced network infrastructure resources, the largest number in that category for any research institution CI technology. The prevalence of researchers at most research institutions would seem sufficient to justify connection to an advanced network, and we anticipated finding those institutions’ bandwidth-intensive research activities at levels like those for high-performance computing resources, CI applications and tools, and data storage and management. We were less surprised at the relatively high non-use reports from teaching institutions, where the level of investment required to acquire and maintain an advanced network connection might be harder to justify.

Lev Gonick, vice president for information technology services and CIO at Case Western Reserve University, explains his research institution’s “Not used” response in this way: “While we use both our National LambdaRail and Internet2 connections for innovation activity, commodity use, and some experimental projects, we are not conducting network-related research that uniquely or exclusively leverages either of those connections.” This helps reinforce our understanding of why the NSF excluded explicit mention of high-capacity data pipes from its CI vision document. The uses of that infrastructure element may simply be too broad to merit specific mention in a vision for advanced research programs. This idea is borne out in other findings in this study, notably in the relative dearth of associations between our advanced network infrastructure-related data and certain other study findings.
Resources for Collaboration within Virtual Communities

The NSF’s *Cyberinfrastructure Vision* devotes an entire section to “Virtual Organizations for Distributed Communities (2006–2010).” The applications and tools it envisions being shared among virtual community members include “experimental facilities and field equipment, distributed instrumentation, sensor networks and arrays, mobile research platforms, high-performance computing systems, data collections, sophisticated analysis and visualization facilities, and advanced simulation tools.” The report also asserts that the establishment of virtual organizations among research groups with common interests is “revolutionizing the conduct of science and engineering research and education.”6

Our findings suggest that this wave is still breaking at our respondent institutions. As Figure 3-7 shows, a majority of teaching institutions report no use of resources for collaboration within virtual communities. And for this technology alone, a majority of research institutions report either no use or occasional use by a few personnel. The remaining research institution responses are fairly evenly spread among the higher-use categories.

As we will see later in this chapter, the current importance that our respondents ascribe to science and engineering use of resources for collaboration within virtual communities is less than for other technologies (Figure 3-10). By contrast, its future importance to research at research institutions is on par with that of the other technologies, and its importance to teaching at research institutions exceeds the importance of any other CI technology (Figure 3-12). We take this as a further suggestion that the collaboration wave NSF envisions is beginning to break.

Sources of Cyberinfrastructure Technologies

Perhaps more than any other technologies, researchers, teachers, and students use CI technologies obtained from and funded by a variety of sources. In some cases—virtual-community teleconferencing systems, for example—the resources may
not be used broadly enough to justify their purchase, support, and ongoing maintenance by the central IT organization. For access to these, researchers may have to invest their own grant funds to purchase them and the time and effort of their own staff and students to support and maintain them. In other cases—for example, many advanced network infrastructure options—economic and logistical factors, including economies of scale, make central IT the logical provider. In yet other cases—the magnitude of cost and of support and maintenance efforts may dictate that regional consortia or government agencies acquire the resource and make it available to members or grantees.

For each of our CI technologies, we asked our survey population to tell us where researchers obtain access and how each technology is funded. For each of five potential sources (the lists differ slightly for the two questions), respondents chose their responses from a five-point scale ranging from “none” to “a very large extent.”

**Obtaining Access**

Figure 3-8 shows fairly consistent patterns in the ways researchers obtain access to high-performance computing, CI applications and tools, and data storage and management resources. A researcher’s own resources (presumably grant money or research lab start-up money) were the most extensive source for obtaining access to high-performance computing, CI applications and tools, and data storage and management, and were the second most extensive source for collaboration resources. For advanced network infrastructure resources and, to a smaller extent, for collaboration resources, central IT was the most extensive source. Central IT was the second most extensive source for high-performance computing, CI applications and tools, and data storage and management. Resources available through collaborations with other higher education institutions were used to the third greatest extent for all technologies, followed by governmental or private resources and “other campus resources.”
Although these findings provide a general picture of decentralization in the provision of the five CI technologies, they also clearly demonstrate that central IT has significant skin of its own in the research game. This is most obviously the case for advanced network infrastructure resources, presumably because it, more than any of the other technologies, underlies the full spectrum of research activities. Moreover, as its treatment in NSF’s Cyberinfrastructure Vision suggests, it is the technology most likely to be taken for granted as a campus “utility.” Also, advanced network infrastructure resources, more than any other technology, are likely to offer a single technological standard (TCP/IP, as the most common example) that is compatible with all or most research systems, making it a good candidate for centralization on economy-of-scale grounds.

Central IT is also the most extensive source for resources for collaboration within virtual communities, though at a smaller scale, followed fairly closely by the individual researcher or research lab’s resources and resources obtained from collaborations. To a smaller extent than for any other of these five CI technologies, researchers obtain access to resources for collaboration from governmental or private resources, perhaps reflecting a lack of penetration of this technology into private and governmental research contexts.

In only a few areas is the source of CI technologies significantly associated with institutional mission. At teaching institutions, researchers are less likely (mean response 2.69) than their colleagues at research institutions (mean response 3.51) to provide their own CI applications and tools resources. Similarly, researchers at teaching institutions are less likely to provide their own data storage and management resources (mean response 2.75) or obtain access to them from other campus resources (mean response 1.80) than their research institution colleagues (mean responses 3.68 and 2.31, respectively).

Researchers at research institutions obtain access to advanced network infrastructure resources from their central IT organizations more than a full point more extensively

---

**Figure 3-8. How Researchers Obtain Access to CI Technologies**

*Scale: 1 = none, 2 = a small extent, 3 = a moderate extent, 4 = a large extent, 5 = a very large extent*
(mean response 4.46), on average, than researchers at teaching institutions (mean response 3.31). We speculate that advanced network infrastructure resources at teaching institutions benefit so few parties that the institution cannot justify acquiring them centrally. This is difficult to substantiate, though, because for no other source of advanced network infrastructure resources were there significant differences between the two types of institutions.

Finally, research institution researchers are more likely, on average, to provide their own collaboration resources (mean response 3.06) or obtain them from other campus resources (mean response 2.28) or from governmental or private sources (mean response 2.21) than are their teaching institution colleagues (mean responses 2.24, 1.86, and 1.81, respectively).

Respondents at most institutions told us that researchers obtained access to CI technologies from diverse sources. In only a few isolated cases did they tell us that central IT was the exclusive source for a given technology. Somewhat larger numbers, however, gave us reason to think that central IT was the predominant provider. To assess predominance, we tallied institutions whose respondents said the extent to which researchers obtained access to the technology from central IT was “a large extent” or “a very large extent” and responded “none” or “a small extent” to our questions about all other sources. Table 3-1 shows the results as counts of institutions where central IT is the predominant provider. The numbers are mostly small (seldom exceeding 10%) relative to the total respondents reporting in a given category. This finding underscores our sense that CI resources supporting research are, for the most part, highly decentralized. The standout exception is for the provision of advanced network infrastructure at research institutions. There, central IT is the predominant provider at more than 30% of institutions.

**Funding Cyberinfrastructure**

For high-performance computing, CI applications and tools, and data storage and management resources, funds awarded to the researcher or the researcher’s lab are the most extensive funding source (see Figure 3-9). Campus central IT organization funds are substantially less important for high-performance computing and CI applications and tools, and somewhat less important for data storage and management resources. For advanced network infrastructure resources, central IT funds are far and away the most extensive source, whereas for collaboration resources they are the most extensive by a smaller margin. For collaboration resources, funds awarded to the researcher are clearly the second most extensive source.

On average, CI technologies are funded to only a small extent by funds awarded to the institution and not specifically for the researcher or lab, other campus funding, and funds made available through collaborations with other higher education institutions.

<table>
<thead>
<tr>
<th>CI Technology</th>
<th>Research Mission</th>
<th></th>
<th>Teaching Mission</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Central IT</td>
<td>Total</td>
<td>Central IT</td>
<td>Total</td>
</tr>
<tr>
<td>High-performance computing</td>
<td>5</td>
<td>125</td>
<td>0</td>
<td>50</td>
</tr>
<tr>
<td>CI applications and tools</td>
<td>2</td>
<td>136</td>
<td>7</td>
<td>108</td>
</tr>
<tr>
<td>Data storage and management</td>
<td>3</td>
<td>134</td>
<td>13</td>
<td>104</td>
</tr>
<tr>
<td>Advanced network infrastructure</td>
<td>39</td>
<td>123</td>
<td>3</td>
<td>58</td>
</tr>
<tr>
<td>Collaboration within virtual communities</td>
<td>11</td>
<td>127</td>
<td>10</td>
<td>98</td>
</tr>
</tbody>
</table>

Table 3-1. Institutions at Which Central IT is the Predominant Provider of CI Technologies
As one might expect, for high-performance computing, CI applications and tools, data storage and management, and collaboration resources, mean responses about funding awarded to the researcher or lab vary significantly with institutional mission (see Table 3-2). Teaching institutions, with less research activity overall, attract lower levels of external research funding, and this, we surmise, is reflected in funding sources for CI technologies there.

Mission is not significantly associated with awards to researchers or labs for advanced network infrastructure resources, but as Table 3-3 illustrates, it is associated with central IT as a source of funding for that technology. At teaching institutions, the mean extent to which central IT funds advanced network infrastructure resources is moderate (3.02); at research institutions the mean exceeds “a large extent” by a fifth of a point (4.21). More than twice as many research institutions (57.4%) as teaching institutions (27.8%) said central IT provided funding for advanced network infrastructure resources to a very large extent. Our data provide no suggestion that any other source of advanced network infrastructure funding is more important than central IT, regardless of mission.

As we did for the sources from which researchers obtain access to CI resources (Table 3-1), we looked at which CI funding source was predominant. In this case we tallied institutions whose respondents said the extent to which a technology was funded by campus central IT funds was “a large extent” or “a very large extent” and the extent to which funding came from all other sources was either “none” or “a small extent.” Table 3-4 shows the results as counts of institutions where central IT was the predominant funding source. In three cases, central IT was the predominant funding source for more than 10% of institutions: data storage and management resources at teaching institutions, and advanced network infrastructure resources at both research and teaching institutions. As with the results reported in Table 3-1, the numbers exceed 30% only for advanced network infrastructure
at research institutions. These findings suggest a little more centralization of funding than of provision, but still in a generally very decentralized context.

**Importance of Cyberinfrastructure Technologies**

Although the NSF tends to speak of CI in terms of science and engineering research, other academic disciplines take an interest in CI as well. To get a sense of how relevant our five CI technologies were to the survey population, we asked about their importance in four contexts: research in science and engineering; research in other disciplines; creative activities such as arts, music, and so on; and teaching and learning. As one might expect, we found that importance to science and engineering was dominant.

Because applications of CI technologies are evolving rapidly and CIOs need to plan for their deployment and support, we also
asked our respondents to tell us how they thought the overall importance of each technology would change during the next three years with regard to its use in research and its use in teaching and learning. With some interesting exceptions, we found that anticipated future importance tracked closely to current importance.

**Current Importance**

Figure 3-10 presents mean reported importance values for each of our five CI technologies in each of the four academic areas we asked about. For all technologies except resources for collaboration within virtual communities, importance to science and engineering was relatively high. For high-performance computing, data storage and management, and advanced network infrastructure, importance was above the midpoint between moderate and high importance. For CI applications and tools it was just below the midpoint. At 3.06, the mean reported importance of collaboration resources to science and engineering barely exceeded moderate and was nearly identical to the importance reported for those resources in teaching and learning (3.05). Thus it appears that the first four technologies are the stuff of science and engineering research; collaboration resources obviously have applications to that academic area, but they are not substantially more important to that area than to the other areas we asked about.

Although high-performance computing and advanced network infrastructure are of the greatest importance to science and engineering research, data storage and management resources and advanced network infrastructure resources appear to be the most important to all other academic areas. Between the areas of science and engineering research and research in other disciplines, the greatest differences we find are in the areas of high-performance computing (1.08 points) and CI applications and tools (0.72 points), presumably reflecting the fact that researchers in other disciplines—the humanities and social sciences, predominantly—have not broadly adopted the computation-intensive modeling and simulation applications that have become so important to science and engineering.

Brian Stewart, CIO at Athabasca University, explains it this way: “For researchers in certain disciplines, there doesn’t seem to be a peer group they can look to that has taken up advanced uses of technology. The resources and expertise are within their reach here, but their level of interest just isn’t high enough to get them engaged. They don’t see yet what benefit those technologies would bring.”

For advanced network infrastructure resources, as well, the difference in mean importance between these areas is relatively large (0.65 points), reflecting scientists’ and engineers’ more frequent use of high-bandwidth connections to remote instruments.
as well as those researchers’ more frequent need to transport large data sets across the network, often in or near real time.

The importance of CI technologies to creative activity is uniformly lowest among the four academic areas we asked about. The pattern is the same for this area as for research in other disciplines: data storage and management and advanced network infrastructure resources are most important, and high-performance computing and CI applications and tools resources are least important. The mean importance of high-performance computing resources to creative activity barely exceeds “minor” (2.07).

Excepting only high-performance computing, the importance of all CI technologies to teaching and learning is ranked about as high as its importance to research in fields other than science and engineering. Data storage and management, advanced network infrastructure, and collaboration resources are the technologies most important to teaching and learning. This high relative importance for collaboration resources probably reflects their value in creating instructional communities among remotely located faculty and students and in supporting access to digital resources.

Figure 3-11 depicts the distinctions between research and teaching institutions with respect to CI technology importance. For each technology, the greatest difference is in the area of science and engineering research: for all technologies, the difference in mean between research institutions and teaching institutions exceeds a full point on our five-point scale. For advanced network infrastructure, it exceeds 1.5 points. Variations for research in other disciplines follow a similar pattern, although the magnitude of the spread exceeds a full point only for data storage and management and advanced network infrastructure.

Not surprisingly, the importance of CI technologies varies significantly by institutional mission in most academic areas. The broad exception is their importance to teaching and learning, where research institutions and

![Figure 3-10. Importance of CI Technologies to Academic Areas](image-url)
Higher Education IT and Cyberinfrastructure

ECAR Research Study 3, 2008

teaching institutions are statistically indistinguishable. We speculate that this is because the teaching and learning mission is common to both types of institutions; it is the presence or absence of a research focus that distinguishes them, not the presence or absence of teaching and learning activities.

Similarly, for creative activities such as art, music, and so on, research institutions are statistically indistinguishable from teaching institutions in terms of the importance of high-performance computing and CI applications and tools, the two CI technologies that seem most closely associated with research in science and engineering. Here, we speculate, it is the comparative irrelevance of the technologies to creative activities that is similar regardless of institutional mission.

Among those technologies for which teaching and research institutions do report statistically different mean levels of importance for use in creative activities—data storage and management, advanced network infrastructure, and collaboration resources—the differences are relatively small, between 0.6 and 0.8 points. This probably reflects the fact that the level of advanced technology use in the creative disciplines is just a bit more uniform across research institutions and teaching institutions.

Figure 3-11 also reveals the relatively high importance of all technologies to research institutions. Whereas Figure 3-9 shows no technology for which mean importance reaches a value of 4.0, “high importance,” Figure 3-11 shows that for research institutions, high-performance computing, CI applications and tools, data storage and management, and advanced network infrastructure are all of high mean importance for research in science and engineering; of these four technology areas, means for all but CI applications and tools substantially exceed 4.0. Again, these four are clearly the current core technologies for research, with collaboration within virtual communities as the exception. Yet as we saw above, NSF’s Cyberinfrastructure Vision for the future of research gives collaboration within virtual communities much more

---

**Figure 3-11. Importance of CI Technologies to Various Activities, by Institutional Mission**

*Scale: 1 = no importance, 2 = minor importance, 3 = moderate importance, 4 = high importance, 5 = very high importance*
than lip service, dedicating a full chapter to it. Did our respondents envision the future importance of collaboration resources rising to the level of the other CI technologies? We will see below.

**Future Importance**

According to NSF’s *Cyberinfrastructure Vision*, “The rapidly evolving nature of CI requires ongoing assessment of current and future user requirements.” In this spirit, we asked our respondents to predict how the overall importance of each CI technology would change during the next three years. We asked them to consider this question in the context of research activities as well as teaching and learning activities. However, we did not ask them to distinguish between research in science and engineering and research in other disciplines, nor did we ask them to consider future importance to creative activities such as art, music, etc.

The results presented in Figure 3-12 exclude reports of anticipated decreases in importance, which represented only a fraction of a percent of respondents for each technology. In all cases, the extent of anticipated change in importance was greater for research institutions than for those reporting a teaching mission. Research institutions consistently anticipated a greater increase in importance for research activities than for teaching, whereas teaching institutions foresaw greater increased importance to teaching than to research.

For research institutions, the greatest extent of anticipated increase (adding “great increase” and “moderate increase”)

![Figure 3-12. Anticipated Change in Importance of CI Technologies, by Institutional Mission](image-url)
was in the importance of data storage and
management resources to research activities. Here, uniquely, more than three-quarters
of respondents at research institutions said they anticipated a great increase in the
technology’s importance to research. While the importance to teaching and learning of
resources for collaboration within virtual communities was also expected to grow
substantially at institutions with a teaching mission, respondents at those institutions
shared research institutions’ feeling that data storage and management would be the top
growth area in teaching activities at their institutions. Athabasca’s Stewart provided
one insight into this by observing, “We’re accumulating huge log files within our
learning management system. Our intention is to begin mining these data and applying
our findings to improving the pedagogic process. I can see that once success emerges
it is going to result in exponentially increasing demand for data resources in teaching and
learning. We’re preparing for that now as we plan enhancements to our storage arrays.”

For research institutions, the second highest growth area for research activi-
ties was advanced network infrastructure. Virtually tied for third place were high-
performance computing, CI applications and tools, and collaboration resources. In
second place for future growth in impor-
tance to research institutions’ teaching and learning activities were collaboration
resources, followed by advanced network infrastructure, CI applications and tools,
and high-performance computing.

Teaching institutions agreed with research institutions that data storage and manage-
ment resources would grow the most in importance to both research and teaching
and learning activities. Nearly tied for second place for research activities were
collaboration resources, advanced network infrastructure, and CI applications and tools,
trailed by high-performance computing. In second place for teaching institutions’
teaching and learning activities were collabora-
tion resources, followed by the nearly tied
group comprising CI applications and tools,
advanced network infrastructure, and high-
performance computing.

The future importance of data storage
and management resources to research and
teaching institutions alike is notable here. This may reflect the pain our respondents
feel as they anticipate not just responsibility for meeting increasing data needs in both
research and teaching and learning as the sheer volume of digital information present
in the academic environment explodes, but also as they anticipate an increasing share of
responsibility for the short- and long-term storage of research data. Historically, the latter
responsibility has fallen more to the individual researcher than it may in the future. Although
the cost of storage continues to decrease on a per-terabyte basis, the complexities of backing
up and archiving what we perceive (for now) to be massive data collections are increasing.
At the same time, the expectations of funding agencies for comprehensive data manage-
ment strategies escalate. Central IT would seem to have a role to play in resolving this
tension, and it looks as though our respon-
dents see it coming.

In most cases, the current importance of a
technology was, to a statistically meaningful extent, positively associated with antici-
pated change in importance. The higher the reported current importance, the higher the
anticipated increase in importance during the next three years. As Table 3-5 shows,
for advanced network infrastructure and collaboration within virtual communities,
current importance and anticipated change in importance went hand in hand for all
academic areas. This may have to do with the overlap of the research use of these
technologies with instructional activities; both technologies are well suited to activities
in either area of scholarship.
These findings are interesting mostly for the exceptions. They signal that the growth trajectories for high-performance computing, especially, but also for CI applications and tools and data storage and management resources, are rather different for research activities compared to teaching and learning. For high-performance computing and CI applications and tools, this interpretation reinforces what we see by scanning Figure 3-10: the current importance of high-performance computing and CI applications and tools to academic areas other than science and engineering research is visibly different from the importance of the other three CI technologies.

On the other hand, Figure 3-10 does not help explain the divergence in trajectories for data storage and management

---

**Table 3-5. Positive Associations between Current Importance and Anticipated Change in Importance**

<table>
<thead>
<tr>
<th>Current Importance of CI Technology</th>
<th>Anticipated Change in Importance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Research Activities</td>
</tr>
<tr>
<td>High-performance computing</td>
<td>✓ ✓</td>
</tr>
<tr>
<td>Research in science and engineering</td>
<td>✓ ✓</td>
</tr>
<tr>
<td>Research in other disciplines</td>
<td>✓ ✓</td>
</tr>
<tr>
<td>Creative activity</td>
<td>✓ ✓</td>
</tr>
<tr>
<td>Teaching and learning</td>
<td>✓ ✓</td>
</tr>
<tr>
<td>CI applications and tools</td>
<td>✓ ✓</td>
</tr>
<tr>
<td>Research in science and engineering</td>
<td>✓ ✓</td>
</tr>
<tr>
<td>Research in other disciplines</td>
<td>✓ ✓</td>
</tr>
<tr>
<td>Creative activity</td>
<td>✓ ✓</td>
</tr>
<tr>
<td>Teaching and learning</td>
<td>✓ ✓</td>
</tr>
<tr>
<td>Data storage and management</td>
<td>✓ ✓</td>
</tr>
<tr>
<td>Research in science and engineering</td>
<td>✓ ✓</td>
</tr>
<tr>
<td>Research in other disciplines</td>
<td>✓ ✓</td>
</tr>
<tr>
<td>Creative activity</td>
<td>✓ ✓</td>
</tr>
<tr>
<td>Teaching and learning</td>
<td>✓ ✓</td>
</tr>
<tr>
<td>Advanced network infrastructure</td>
<td>✓ ✓</td>
</tr>
<tr>
<td>Research in science and engineering</td>
<td>✓ ✓</td>
</tr>
<tr>
<td>Research in other disciplines</td>
<td>✓ ✓</td>
</tr>
<tr>
<td>Creative activity</td>
<td>✓ ✓</td>
</tr>
<tr>
<td>Teaching and learning</td>
<td>✓ ✓</td>
</tr>
<tr>
<td>Collaboration within virtual communiti</td>
<td>✓ ✓</td>
</tr>
<tr>
<td>Research in science and engineering</td>
<td>✓ ✓</td>
</tr>
<tr>
<td>Research in other disciplines</td>
<td>✓ ✓</td>
</tr>
<tr>
<td>Creative activity</td>
<td>✓ ✓</td>
</tr>
<tr>
<td>Teaching and learning</td>
<td>✓ ✓</td>
</tr>
</tbody>
</table>

✓ Significant positive association
*
Marginal significance
resources that we infer from the blank cells in Table 3-5. The pattern for that technology in Figure 3-10 is similar to that for advanced network infrastructure, and, at least for the nonscience and engineering areas, for collaboration resources. In the end, we are probably safest simply acknowledging that advanced network infrastructure and collaboration resources are of more general utility across all academic disciplines than the triumvirate of high-performance computing, CI applications and tools, and data storage and management resources. We speculate that this difference adequately explains the variance in the trajectories of the latter technologies by institutional mission.

Summary and Implications

Use of our five core CI technologies is fairly abundant in higher education. About two-thirds of respondents to our survey reported at least some research use of CI applications and tools, data storage and management resources, and resources for collaboration within virtual communities. Perhaps owing to the price of admission or the steepness of the learning curve, fewer (just under half) were making any use of high-performance computing resources or advanced network infrastructure for research. As we would expect, institutions whose missions focus on research are far more likely to use CI technologies—and to use all five of them—than institutions where the focus is more on teaching.

Looking at where researchers obtain access to CI resources, and where funding for them comes from, we reveal only what is in plain sight for most CIOs: although the central IT organization is an important player in providing and funding CI resources, researchers have several other options and often use them. For three CI technologies—high-performance computing, CI applications and tools, and data storage and management resources—the individual researcher or lab plays the strongest role as provider and funder. The strongest roles for central IT, in this context, are in providing and funding advanced network infrastructure and, to a lesser extent, data storage and management resources. In general, these roles are not significantly different for research and teaching institutions.

If an institution’s goal is the integration of CI technologies to provide seamless support for research, it is clear from our data that CIOs need to exert influence far beyond their own organizations. As we will see in Chapter 6, our respondent population gave lackluster marks to the collaborative tendencies of researchers, to institutional incentives for collaborative practices, and to their own effectiveness in integrating CI resources. The CIO position is increasingly one that requires outreach, diplomacy, and institutional-level leadership. The CI context seems no exception.

Our respondents tell us that all CI technologies except resources for collaboration within virtual communities are, by substantial margins, of greatest importance to research in science and engineering. Their importance to research in other disciplines and to teaching and learning activities is generally about equal, with the exception of high-performance computing, which is more important to research in other disciplines. CI technologies seem to have the least importance to creative activities, though the margins of difference between that area and the others are substantial only for high-performance computing and CI applications and tools. As CIOs consider which alliances to build in pursuit of an integrated suite of CI tools and services, researchers in science and engineering would be key candidates, but these data suggest that digital scholars in all four of our academic areas are likely to feel they have a stake in the resulting initiatives.
Among research institutions, the anticipated future importance of all CI technologies is rated higher than among teaching and learning institutions. Research institutions rate the future importance of CI technologies to teaching activities lower than their future importance to research. Teaching institutions, on the other hand, anticipate that the importance of CI technologies to teaching and learning will increase more than their importance to research. Although these findings all appear to express confidence that change is coming in the next three years in the form of increased opportunities to apply CI resources to research and instruction, the mean change our respondents anticipate substantially exceeds “moderate increase” only for research activities at research institutions. Although changes there may include disruptive—even revolutionary—elements, such changes seem less likely at institutions where research takes a lower priority.

Endnotes
2. NSF describes petascale computing as executing “10^{15} operations per second with comparable storage and networking capacity.” Ibid., 1.
3. Ibid., 17.
4. Ibid., 21.
7. Only the academic areas for which significant differences emerged are reported here.
8. National Science Foundation, Cyberinfrastructure Vision, 35.
Understanding the Cyberinfrastructure Landscape

Knowledge is of two kinds. We know a subject ourselves, or we know where we can find information upon it.
—Samuel Johnson

Key Findings

- Of the five CI technologies, CIOs say they are most knowledgeable about advanced network infrastructure resources; they say they are least knowledgeable about CI applications and tools.
- For all CI technologies, the CIO’s knowledge about them increases with the extent to which central IT provides access to and funding for the technology.
- Among five areas of detailed knowledge, CIOs know the most about what CI resources are available to researchers, who provides them, and who funds them; they know the least about who is using them and what they are used for.
- More than three-quarters of respondents rate the CIO’s ability to obtain information about CI technologies as good or better; the better they rate ability to obtain information, the better they rate the CIO’s overall knowledge.
- Mean ability to obtain information about all CI technologies is higher than the mean knowledge level of the CIO, suggesting good opportunities for CIOs to learn more.
- About 10% of institutions reporting that they use CI technologies have complete inventories of resources for CI tools and applications, data storage and management resources, and resources for collaboration within virtual communities. Twice as many report complete inventories for high-performance computing resources; five times as many do for advanced network infrastructure resources.
- The CIO’s overall knowledge about each CI technology is greater where the institution’s documented inventory of that technology is more complete.
- For high-performance computing and CI applications and tools, respondents on average rate the CIO’s knowledge level below that of the chief research officer (CRO) and science and engineering deans; for the other three technologies, respondents rate the CIO’s knowledge level higher than that of four other executives.

Knowledge about CI technologies is crucial for those actually engaged in research, but is it necessary for CIOs? Can they do a better job of integrating research IT resources if they understand the technologies themselves? And what about other campus executives? Does their familiarity with CI technologies contribute to successful outcomes? To help
answer these questions, we asked survey respondents to evaluate the knowledge of the CIO and various other officers about CI technologies. We discuss our findings below, then in Chapter 6 we explore the associations of executive knowledge with success in CI support.

As we have suggested before, higher education research efforts at most institutions have traditionally been more decentralized than centralized, so it has been difficult at some institutions for the CIO to obtain information about the use of cyberinfrastructure technologies. Our findings show that this is still the case and that it affects support.

One ingredient in the successful management of IT services is a detailed, dynamic inventory of the IT resources being supported. The IT Infrastructure Library refers to this as a configuration management database and considers it to be an integral part of all other service management processes.1 For respondent institutions, our survey gathered an inventory of inventories of CI resources and revealed patterns of association with various practices.

Because CI applications cross institutional boundaries in several dimensions, the knowledge level of the CIO is only one indicator of the state of the research enterprise. We also found scattered, but statistically significant, associations between the level of knowledge of other senior administrators and a number of CI success factors.

CIO’s Knowledge

The CIO’s level of knowledge about CI technologies is key to our understanding of CI as an enterprise activity. To the extent that campus culture permits the centralization of CI resources, the central IT organization is probably the most efficient place on campus to focus them. How much the leader of that organization knows about the use of CI technologies bears upon the state of integration of CI resources now and at least hints at the potential for future integration.

As we learned in Chapter 2 (Figure 2-3), 77.0% of our respondents were themselves CIOs. At least a few respondents who reported other roles were also CIOs, so in a preponderance of cases, the findings we report in this section represent self-assessments whose level of objectivity, naturally, may not be perfect. Nor can we assume that the non-CIO respondents were free of the biases inherent in making the subjective assessments we asked for. Nevertheless, we trust that our respondents were well informed about conditions at their institutions and that their responses are somewhere close to reality.

Overall Knowledge

For each of the five core CI technologies, we asked respondents to rate the CIO’s level of overall knowledge of the research use of that technology at the responding institution. Figure 4-1 presents the results, which follow a fairly normal, bell-shaped distribution for most technologies. The exceptions, high-performance computing and advanced network infrastructure, are both skewed positively, with 45.5% and 61.3% of respondents, respectively, reporting very good or excellent knowledge. The latter result should come as no surprise; as we saw in Chapter 3, the central IT organization is the source of advanced network infrastructure resources to a greater extent than any other technology. As primary provider of the resource, the CIO should be very knowledgeable about it. In fact, the CIO’s knowledge about all five technologies is strongly associated with the extent to which researchers obtain access to those technologies through the central IT organization and to which central IT funds them.

Table 4-1 provides means and standard deviations for the CIO’s level of knowledge about each of the five technologies. (Numbers of respondents, represented in the column headed “N,” vary widely because, as we saw in Chapter 3, not all respondents are currently using all of the technologies.)
The CIO’s overall knowledge of CI technologies was not significantly associated with institutional mission except for knowledge of advanced network infrastructure, where mean knowledge of leaders at teaching institutions was 3.25 (a little better than “good”) and at research institutions was 4.02 (“very good”). This fits with our finding, reported in Chapter 3, that researchers at research institutions are significantly more likely than those at teaching institutions to obtain access to advanced network infrastructure resources from central IT. It seems logical that where advanced network infrastructure access is more extensively obtained from central IT, the CIO would be more knowledgeable about it.

This principle can be extended to all five of our CI technologies, as Figure 4-2 shows. The greater the extent to which researchers obtain a technology from the central IT organization, the higher the CIO’s (usually self-reported) level of knowledge about it. The spread between highest and lowest mean levels of knowledge within the first four technologies portrayed in Figure 4-2 is shown in Table 4-1.

**Table 4-1. CIO’s Mean Overall Knowledge about the Research Use of CI Technologies**

<table>
<thead>
<tr>
<th>CI Technology</th>
<th>N</th>
<th>Mean Level of Knowledge*</th>
<th>Std. Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>High-performance computing</td>
<td>178</td>
<td>3.26</td>
<td>1.106</td>
</tr>
<tr>
<td>CI applications and tools</td>
<td>246</td>
<td>2.84</td>
<td>1.093</td>
</tr>
<tr>
<td>Data storage and management</td>
<td>236</td>
<td>3.14</td>
<td>1.079</td>
</tr>
<tr>
<td>Advanced network infrastructure</td>
<td>181</td>
<td>3.77</td>
<td>1.065</td>
</tr>
<tr>
<td>Collaboration within virtual communities</td>
<td>223</td>
<td>3.04</td>
<td>1.098</td>
</tr>
</tbody>
</table>

*Scale: 1 = poor, 2 = fair, 3 = good, 4 = very good, 5 = excellent
this figure ranges from 1.11 and 1.12 points for data storage and management resources and CI applications and tools, respectively, to 1.34 points for high-performance computing. For collaboration resources the spread is considerably smaller, 0.81 points, suggesting diminishing returns in terms of the CIO’s knowledge as central IT provides increasing levels of access to collaboration resources or, to speculate more broadly, suggesting some sort of ceiling on the “knowability” of the collaboration area.

The CIO’s overall knowledge of each of the CI technologies varies in the same way with the extent to which central IT is the funding source for the technology.

**Detailed Knowledge**

In addition to respondents’ assessment of the CIO’s overall knowledge of the technologies’ use, we asked for assessments of five specific areas of knowledge:

- What resources are available to researchers
- Who provides these resources
- Who funds these resources
- Who is using these resources
- What they are being used for

Figure 4-3 shows that knowledge levels are generally highest for the first three of these knowledge areas and lower for the last two. The first three are primarily logistical in nature, and it seems logical that a provider of resources would know about them. The fourth area, “who is using these resources,” is a bit more specific, but it’s also essentially logistical and, as we might expect, we find that knowledge levels for that area are between the levels for the more purely logistical areas and those for the last area, what these resources are used for. Knowledge in the latter area would reflect a higher level of personal interest in the research per se, and so slightly lower mean knowledge ratings are consistent with our sense that CIOs are generally too busy to take so active an interest in the specifics of research projects. Nevertheless, lack of knowledge here may limit central IT’s ability to plan and support CI resources; this finding may represent an area of particular weakness in our survey population. Perhaps a compensating factor is the level of knowl-
edge of certain of the CIOs’ subordinates; our survey did not ask about that.

The CIO’s ability to obtain information about the research use of CI resources hints at both the level of interest the CIO has in research and the levels of trust and respect the research community has for central IT. Reassuringly, Figure 4-4 shows that majorities of our respondents (albeit slim ones in some cases) felt that their ability to obtain that information about four of the five CI technologies was very good or excellent. Even for collaboration resources, where agreement was lowest, 46.2% of respondents felt their ability to obtain information was very good or excellent. Means for the five technologies range between a low of 3.43 for collaboration resources and a high of 3.89 for advanced network infrastructure resources, on our five-point scale.

Table 4-2 provides means and standard deviations for the CIO’s ability to obtain information about each of the five technologies.

In a welcome, if fleeting, reaffirmation of our grip on reality, we found that for all five technologies, the better the CIO’s ability to obtain information, the higher the CIO’s level of knowledge about it. As Table 4-3 shows, the baseline mean level of knowledge of advanced network infrastructure (for those whose ability to obtain it was poor or fair) was 2.31, between fair and good. This is about a third of a point higher than the equivalent mean for any other CI technology, where means tended to indicate fair knowledge or poorer. Where ability to obtain information is rated very good or excellent, the advanced network infrastructure mean of 4.20, significantly above very good, is at least a third of a point higher than that for any other technology and almost ninetenths of a point higher than the mean for CI applications and tools. Table 4-3 presents the analysis for research and teaching institutions combined; controlling for mission yields this same highly significant pattern of results for each type of institution, although mean level of knowledge is consistently lower for teaching institutions.

---

*Scale: 1 = poor, 2 = fair, 3 = good, 4 = very good, 5 = excellent*
Although these findings indicate that ability to know is associated with level of knowledge, they leave open the question of why mean levels of overall knowledge (Table 4-1) are lower for all technologies except advanced network infrastructure than mean reported ability to obtain knowledge (Table 4-3). A glib interpretation might be that respondents are saying the CIO could know about the use of CI technologies in research but cannot be bothered to do so. The more thoughtful interpretation may be that the CIO’s stated ability to obtain knowledge is a reflection of the actual knowledge of someone else on the CIO’s staff. The CIO’s knowledge about the use of CI technologies may be limited, but a subordinate’s greater level of knowledge proves that it is obtainable.

The CIO’s ability to obtain information is significantly associated with institutional mission only for advanced network infrastructure, where, as with the CIO’s level of knowledge, the mean for research institutions is higher than for teaching institutions. Table 4-4 provides details. Again, this probably reflects disparate roles of central IT in providing researchers with access to advanced network infrastructure.

Table 4-2. CIO’s Mean Ability to Obtain Information about the Research Use of CI Technologies

<table>
<thead>
<tr>
<th>CI Technology</th>
<th>N</th>
<th>Mean Ability to Obtain Information*</th>
<th>Std. Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>High-performance computing</td>
<td>179</td>
<td>3.70</td>
<td>1.126</td>
</tr>
<tr>
<td>CI applications and tools</td>
<td>247</td>
<td>3.51</td>
<td>1.165</td>
</tr>
<tr>
<td>Data storage and management</td>
<td>237</td>
<td>3.65</td>
<td>1.077</td>
</tr>
<tr>
<td>Advanced network infrastructure</td>
<td>180</td>
<td>3.89</td>
<td>1.028</td>
</tr>
<tr>
<td>Collaboration within virtual communities</td>
<td>223</td>
<td>3.43</td>
<td>1.133</td>
</tr>
</tbody>
</table>

*Scale: 1 = poor, 2 = fair, 3 = good, 4 = very good, 5 = excellent
The existence of complete inventories of CI technology resources would suggest good things about the level of openness concerning the use of those technologies on campus and, we speculated, might be either an enabler or an outcome (or both) of successful central IT support for research. We asked respondents to describe the status of their institutions’ inventories of CI resources used for research. The three options we offered were no inventory, an inventory for some resources, and an inventory for all resources. Results appear in Figure 4-5.

Clearly, the CI technology most completely inventoried was advanced network infrastructure resources. Almost half of respondents told us their institutions have inventories for all advanced network infrastructure resources. Whatever the source from which researchers obtain advanced network infrastructure

<table>
<thead>
<tr>
<th>Ability to Obtain Information about the Research Use of CI Technologies</th>
<th>N</th>
<th>Mean*</th>
<th>Std. Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>High-performance computing</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Poor/fair</td>
<td>29</td>
<td>2.03</td>
<td>0.778</td>
</tr>
<tr>
<td>Good</td>
<td>43</td>
<td>2.72</td>
<td>0.734</td>
</tr>
<tr>
<td>Very good/excellent</td>
<td>105</td>
<td>3.83</td>
<td>0.914</td>
</tr>
<tr>
<td>Total</td>
<td>177</td>
<td>3.27</td>
<td>1.109</td>
</tr>
<tr>
<td>CI applications and tools</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Poor/fair</td>
<td>45</td>
<td>1.84</td>
<td>0.852</td>
</tr>
<tr>
<td>Good</td>
<td>76</td>
<td>2.61</td>
<td>0.750</td>
</tr>
<tr>
<td>Very good/excellent</td>
<td>124</td>
<td>3.33</td>
<td>1.049</td>
</tr>
<tr>
<td>Total</td>
<td>245</td>
<td>2.83</td>
<td>1.087</td>
</tr>
<tr>
<td>Data storage and management</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Poor/fair</td>
<td>35</td>
<td>1.91</td>
<td>0.612</td>
</tr>
<tr>
<td>Good</td>
<td>68</td>
<td>2.76</td>
<td>0.775</td>
</tr>
<tr>
<td>Very good/excellent</td>
<td>131</td>
<td>3.66</td>
<td>0.966</td>
</tr>
<tr>
<td>Total</td>
<td>234</td>
<td>3.14</td>
<td>1.081</td>
</tr>
<tr>
<td>Advanced network infrastructure</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Poor/fair</td>
<td>16</td>
<td>2.31</td>
<td>0.946</td>
</tr>
<tr>
<td>Good</td>
<td>51</td>
<td>3.24</td>
<td>0.815</td>
</tr>
<tr>
<td>Very good/excellent</td>
<td>112</td>
<td>4.20</td>
<td>0.879</td>
</tr>
<tr>
<td>Total</td>
<td>179</td>
<td>3.75</td>
<td>1.063</td>
</tr>
<tr>
<td>Collaboration within virtual communities</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Poor/fair</td>
<td>44</td>
<td>1.95</td>
<td>0.714</td>
</tr>
<tr>
<td>Good</td>
<td>75</td>
<td>2.77</td>
<td>0.669</td>
</tr>
<tr>
<td>Very good/excellent</td>
<td>101</td>
<td>3.69</td>
<td>1.037</td>
</tr>
<tr>
<td>Total</td>
<td>220</td>
<td>3.03</td>
<td>1.095</td>
</tr>
</tbody>
</table>

*Scale: 1 = poor, 2 = fair, 3 = good, 4 = very good, 5 = excellent
resources, it appears that substantial numbers of CIOs are confident that their institutions are tracking them all. No doubt it helps that, as we learned in Chapter 3, central IT is the dominant source of advanced network infrastructure resources for research.

Our respondents reported relatively high levels of completed inventories for high-performance computing resources too, at just under 23%. Inventories of all CI applications and tools, data storage and management resources, and collaboration resources hovered around 10%.

For all CI technologies, the CIO’s knowledge about their institutions’ research use is better where the inventory of the technology is more complete (see Table 4-4). As we will see in Chapter 6, the CIO’s knowledge about research use of high-performance computing and CI applications and tools is associated with collaborative practices among researchers, incentives for sharing research resources with other campus researchers and for partnering with central IT to achieve economies of scale, and with central IT’s effectiveness at integrating CI resources in support of research.

### Table 4-4. CIO’s Overall Knowledge of and Ability to Obtain Information about the Research Use of Advanced Network Infrastructure, by Institutional Mission

<table>
<thead>
<tr>
<th>Primary Institutional Mission</th>
<th>N</th>
<th>Mean*</th>
<th>Std. Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Overall knowledge</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Research</td>
<td>123</td>
<td>4.02</td>
<td>1.008</td>
</tr>
<tr>
<td>Teaching</td>
<td>57</td>
<td>3.25</td>
<td>1.005</td>
</tr>
<tr>
<td>Total</td>
<td>180</td>
<td>3.77</td>
<td>1.067</td>
</tr>
<tr>
<td><strong>Ability to obtain information</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Research</td>
<td>122</td>
<td>4.11</td>
<td>0.969</td>
</tr>
<tr>
<td>Teaching</td>
<td>57</td>
<td>3.46</td>
<td>1.019</td>
</tr>
<tr>
<td>Total</td>
<td>179</td>
<td>3.90</td>
<td>1.028</td>
</tr>
</tbody>
</table>

*Scale: 1 = poor, 2 = fair, 3 = good, 4 = very good, 5 = excellent*
We began this section suggesting that inventories might enable successful research-support outcomes; although they don’t make an airtight case for it, the associations shown in Table 4-5 do suggest that working toward a complete inventory of CI resources may raise the CIO’s level of knowledge and thus, perhaps indirectly, improve performance related to those variables.

In a way similar to that portrayed in Table 4-5, inventory status is also positively associated with several of our findings from Chapter 3, such as central IT as the entity that provides access to and funding for the CI technologies. This makes sense: the greater the extent to which central IT provides a technology, the easier it should be for central IT to maintain a complete inventory of it. But inventory status is also associated with several findings unrelated to central IT’s control of resources. These include, for all CI technologies, the level of research use of each technology, the importance of the technology to research in science and engineering, and the technology’s future importance to research in general.

Table 4-5. CIO’s Knowledge of the Research Use of CI Technologies, by Inventory Status

<table>
<thead>
<tr>
<th>Inventory Status</th>
<th>N</th>
<th>Mean Level of Knowledge*</th>
<th>Std. Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>High-performance computing</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No inventory</td>
<td>51</td>
<td>2.57</td>
<td>0.944</td>
</tr>
<tr>
<td>Inventory of some resources</td>
<td>82</td>
<td>3.43</td>
<td>0.943</td>
</tr>
<tr>
<td>Inventory of all resources</td>
<td>40</td>
<td>3.90</td>
<td>1.128</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>173</td>
<td>3.28</td>
<td>1.103</td>
</tr>
<tr>
<td><strong>CI applications and tools</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No inventory</td>
<td>98</td>
<td>2.32</td>
<td>0.970</td>
</tr>
<tr>
<td>Inventory of some resources</td>
<td>117</td>
<td>3.12</td>
<td>0.948</td>
</tr>
<tr>
<td>Inventory of all resources</td>
<td>27</td>
<td>3.63</td>
<td>1.275</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>242</td>
<td>2.85</td>
<td>1.098</td>
</tr>
<tr>
<td><strong>Data storage and management</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No inventory</td>
<td>98</td>
<td>2.72</td>
<td>0.993</td>
</tr>
<tr>
<td>Inventory of some resources</td>
<td>113</td>
<td>3.41</td>
<td>1.023</td>
</tr>
<tr>
<td>Inventory of all resources</td>
<td>19</td>
<td>3.84</td>
<td>1.119</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>230</td>
<td>3.15</td>
<td>1.085</td>
</tr>
<tr>
<td><strong>Advanced network infrastructure</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No inventory</td>
<td>39</td>
<td>2.87</td>
<td>1.080</td>
</tr>
<tr>
<td>Inventory of some resources</td>
<td>54</td>
<td>3.69</td>
<td>0.948</td>
</tr>
<tr>
<td>Inventory of all resources</td>
<td>85</td>
<td>4.24</td>
<td>0.840</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>178</td>
<td>3.77</td>
<td>1.067</td>
</tr>
<tr>
<td><strong>Collaboration within virtual communities</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No inventory</td>
<td>98</td>
<td>2.59</td>
<td>0.929</td>
</tr>
<tr>
<td>Inventory of some resources</td>
<td>91</td>
<td>3.26</td>
<td>0.998</td>
</tr>
<tr>
<td>Inventory of all resources</td>
<td>26</td>
<td>4.12</td>
<td>1.071</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>215</td>
<td>3.06</td>
<td>1.094</td>
</tr>
</tbody>
</table>

*Scale: 1 = poor, 2 = fair, 3 = good, 4 = very good, 5 = excellent
For advanced network infrastructure and collaboration resources only, inventory status is also strongly associated with the importance of the technology to other research, to creative activity, and to teaching and learning. These academic areas are traditionally more reliant on central IT than are researchers in science and engineering. As we saw in Figures 3-8 and 3-9, central IT is the most extensive provider and funding source for network infrastructure and collaboration resources, so it makes sense that inventories for them would be better where scholars find them more important.

Other Executives’ Knowledge

Because of the traditional cottage-industry nature of higher education research, and because research has such a high profile at many institutions, it seemed improbable that the CIO would be the only significant repository of CI technology knowledge among the institution’s senior administrators. As Figure 4-6 shows, not only do our respondents believe that other administrators have a level of understanding similar to that of the CIO, but in two cases (high-performance computing and CI applications and tools) the mean reported levels of knowledge for science and engineering deans and chief research officers are actually higher than those of the CIOs.

In general, our respondents felt that CIOs, science and engineering deans, and chief research officers (CROs) were relatively well informed. Chief academic officers (CAOs) rated relatively poorly, and the level of knowledge of “Other deans” was uniformly much lower.

These findings did not vary significantly with institutional mission or with the primary role of the respondent within the institution (reported in Chapter 2). When we discuss collaborative practices and central IT’s success at integrating CI resources in support of research in Chapter 6, however, we will see that those findings are associated with the knowledge levels of CAOs, CROs, and science and engineering deans about high-performance computing, CI applications and tools, and data storage and management resources.

Summary and Implications

The conclusion that emerges from our findings about the CIO’s knowledge of CI technologies is that the CIO knows most about those technologies when the central IT organization provides them. Although this is understandable and, to a degree, inevitable, it carries implications for the CIO’s ability to oversee the successful integration of diverse CI resources in support of research. We understand that the CIO may have subordinates who are much more knowledgeable about CI technologies, but findings we will discuss in Chapter 6 suggest that effective integration of CI resources is positively associated with the CIO’s own knowledge about the technologies.

In many circles, it is axiomatic that CI is so diffuse and so complex that it is essentially unknowable to the higher education CIO. Our data suggest otherwise. On average, CIOs rank their existing knowledge in most areas as good and their ability to obtain information about CI technologies in all areas as solidly between good and very good.

It may be argued that the comparison between existing and potential knowledge is invalid; one unit of ability to know may not have the same weight as one unit of knowledge acquired. But if we take the data at face value, the discrepancy may just represent a sage admission on the part of the respondents (recalling that three-quarters of them were CIOs or equivalent) that there is always more the CIO could learn. We do find for each of the CI technologies that the CIO’s ability to obtain information is positively associated with reported level of knowledge. That, in turn, is associated with the positive outcomes discussed in Chapter 6,
suggesting that a more open environment, in which information about the use of CI technologies is readily shared between researcher and CIO, is one in which those technologies are used more efficiently and are integrated more effectively.

Another indicator of environments in which CI technology information is readily shared is the status of the institution’s inventory of CI resources. Where the inventory was more complete, the CIO’s knowledge was significantly better. The extent to which central IT was the provider or funder of a given technology, of course, was positively associated with inventory status; it’s easiest to count the chickens in your own yard.

Respondents seemed to feel that CROs and science and engineering deans were substantially more knowledgeable about CI technologies than CAOs or deans in nonscience, nonengineering disciplines. Their estimation that, on average, the CRO and science and engineering deans knew even more than the CIO did about high-performance computing and CI applications and tools, if accurate, suggests an awareness among CIOs that management of CI technologies does attract—and perhaps an acknowledgment that it requires—executive attention.

**Endnote**

5

Cyberinfrastructure Underpinnings: Support for Support

Few things can help an individual more than to place responsibility on him, and to let him know that you trust him.
—Booker T. Washington

Key Findings

- Respondents say the CIO is the officer the CEO most often holds primarily accountable for all eight of the research-related service and infrastructure activities in this study.
- When the CIO is the accountable party, the authority and the resources he/she has available to meet responsibilities in those areas are more likely to be sufficient.
- Respondents agree that the CIO’s authority is more often sufficient than the resources he/she can draw upon.
- For all CI technologies, more funding for central IT infrastructure and services would help the most in support for research. This is especially true for data storage and management resources, advanced network infrastructure resources, and services related to collaboration within virtual communities.
- Along with more funding, respondents identified better communication and outreach between researchers and central IT as an aid to more effective research support.
- Substantial numbers of respondents identified a greater role for central IT in the grant budgeting process as yielding improved support for research use of CI technologies.

Most of us know what it feels like to be held accountable for something but not have the authority or the resources to meet our responsibility for it. At best, it’s an opportunity for growth in one’s skills at persuasion and negotiation. At worst, it’s a recipe for personal or even institutional failure.

At many institutions, support for CI activities is decentralized and informal, and this would seem to be fertile ground for mismatches between service expectations and delivery. To help shed light on this, our survey asked whom the institution’s CEO held accountable for eight service and infrastructure activities related to CI resources. Of course, the CEO isn’t the only member of the campus community who has expectations of the CIO or who, depending on the issue, can hold the CIO accountable. For example, when more cordial negotiations have failed, the CIO might be tempted to complain to the research vice president that housing and supporting the
A campus researcher has just acquired a supercomputer with grant funding. They describe it as “yet another unfunded mandate.” Finding mutually beneficial resolutions to situations like that is an art—and not all of us are artists.

Similarly, the CIO’s authority with regard to the central IT machine room might be clear, but when the security of a server located in a research department has been compromised, the CIO may have to take some personal political risks to intervene and do what’s needed to protect the rest of the network.

Resource mismatches are also part of the IT support landscape. For example, high-performance computing clusters in research labs may proliferate as a function of grant revenue, but support personnel in the central IT organization rarely do.

To get at these issues and their relation to the success of CI support, we asked a series of questions about accountability and sufficiency of both authority and resources for each of the following representative research-related service and infrastructure activities.

**Service activities:**
- Providing support services for research IT systems, such as system administration, identity management, and help desk
- Providing security for research systems
- Providing ongoing maintenance and support for IT resources obtained with one-time research funds
- Enforcing the research community’s compliance with national regulations regarding privacy of data, such as HIPAA and FERPA in the United States

**Infrastructure activities:**
- Providing sufficient network bandwidth for research
- Providing sufficient network bandwidth for teaching and learning
- Providing sufficient storage for research data
- Providing space and environmental support for research IT resources owned by campus entities other than central IT

In this chapter, we discuss the responses to those questions and to a set of questions about additional resources and other commitments that might improve central IT support for each of our five CI technologies.

**Accountability**

At most higher education institutions, the CIO or equivalent position is accountable for providing most elements of the IT service and infrastructure landscape. ECAR recently documented this in its study *Service on the Front Line: The IT Help Desk in Higher Education*, in which we reported that at respondent institutions 92% of infrastructure elements and 76% of support services (from lists ECAR supplied) were provided by the central IT organization. For each item among the research-related service and infrastructure activities listed above, we asked respondents to the present study to tell us who the CEO held accountable. The options we gave were individual researchers and academic deans; the chief academic officer (CAO), the chief financial officer (CFO), the CIO, and the chief research officer (CRO) or their equivalents; and “other.”

For all activities, the CIO was the officer most often reported to be accountable. For most activities the margin was wide, although for enforcement of the research community’s compliance with national privacy regulations and for providing space and environmental support for research systems, a variety of other officers were accountable at substantial numbers of institutions.

**Research-Related Service Activities**

Most of our respondents tell us that the CIO is the person the CEO holds primarily accountable for the research-related services on our list. As Figure 5-1 shows, majorities report that the CIO is the officer accountable for providing support services and security for...
research IT systems, as well as ongoing maintenance and support for IT resources obtained with one-time research funds. Just over a third report that the CIO is primarily accountable for enforcing the research community’s compliance with national regulations about data privacy, such as HIPAA and FERPA; the other officers most often reported as primarily accountable for compliance were the CRO and the CAO.

This suggestion of a pivotal role for central IT in providing support services and security for research systems strikes us as reasonable. Central IT is likely to have particular expertise in these areas, and widespread CIO accountability for them signals an efficient use of institutional resources. Where the individual researcher is held primarily accountable for them, it is likely that graduate students do much of the work. Speaking to the centralized-versus-decentralized support question that this implies, Thomas Hacker, assistant research professor at Purdue University, and Bradley Wheeler, vice president for information technology and CIO at Indiana University, observe that “the redirection of productive graduate student energies into providing support represents a hidden drain on the vitality of the institutional research enterprise. It makes better sense for graduate students to focus on activities in which they are most productive—research—rather than on activities that could be provided more effectively by professional staff.”

We were a little surprised that so many institutions named the CIO as primarily accountable for ongoing maintenance and support of IT resources obtained with one-time funds. All research systems need at least a little post-purchase care and feeding, but we expected more accountability for those activities to fall to the individual researcher whose grant was most likely the source of the one-time purchase funds. We also suspected that accountability for ongoing maintenance would often fall to the CRO, whose staff were presumably involved in designing and approving the grant’s budget and who may have boosted the proposal’s chances of success through a promise of matching funds.
In some campus cultures, no doubt, the CIO sees the opportunity to take on support of research IT resources as a rewarding challenge for the central IT staff, as the fulfillment of an expected obligation, and/or as an opportunity to acquire political capital. In other cultures, though, the support burden may simply feel like another technological mouth to feed from a static or shrinking central IT budget. Where a grant-funded IT resource is highly specialized and has little in common with the other resources managed by central IT, the maintenance and support burden is greater, and if the CIO was unaware that the resource was being acquired or had no involvement in selecting the resource, the sense of unfunded mandate can be very strong indeed.

Accountability for the enforcement of privacy regulations is the most broadly distributed of the findings depicted in Figure 5-1. Because it is a policy issue rather than a technology issue, success in this service activity would not seem to require the CIO’s attention, and indeed only a third of respondents said the CIO was accountable for it. However, even this relatively low level of CIO involvement was higher than we expected. Unlike accountability for ongoing maintenance of research IT resources, where the CIO can bring technical resources to bear, the determining factors here are almost certainly more political than practical.

Supporting this interpretation, Kathleen Bauer, assistant vice provost for academic information at the University of Michigan, explained, “As a widely decentralized institution, the University of Michigan involves groups of individuals from across campus who collaborate to solve these issues. No one person has responsibility to ensure compliance. For example, HIPAA compliance is coordinated by the hospital compliance officer, who works with others from the Office of the General Counsel, the Privacy Committee, IT Security, etc. FERPA compliance is coordinated by our registrar, again working with others from the Office of the General Counsel, the Privacy Committee, IT Security, and so forth.”

Research-Related Infrastructure Activities

According to our respondents, the CEO holds the CIO accountable for providing sufficient bandwidth for research and for teaching and learning at more institutions than for any of the other research-related activities we discuss in this chapter (see Figure 5-2). Providing storage for research data is also commonly the CIO’s responsibility, although at 16.8% of respondent institutions, individual researchers are held primarily accountable for this activity instead.

At just over a third of institutions, CIOs are accountable for providing space and environmental support for research IT resources owned by entities other than central IT, in sharp contrast to the 81.2% who are held accountable for providing support services for them (see Figure 5-1). This implies that the bulk of central IT support services for research systems are delivered at locations not controlled by the CIO. At other institutions, several other officers are accountable for space and environmental support, including academic deans at 21.9% of institutions, representing the highest accountability numbers for those officers among all eight activities. CAOs, in some cases, are primarily accountable for providing space and environmental support, as are individual researchers.

Variations in Accountability, by Institutional Mission

Accountability for several research-related activities is significantly associated with institutional mission. Where research is the mission, officers other than the CIO are often accountable for two of our eight activities: providing space and environmental support for research IT resources owned by other campus entities (academic deans are accountable more
often than CIOs), and enforcing the research community’s compliance with national regulations regarding privacy (CROs are accountable as often as CIOs). Where teaching is the mission, however, the CIO is most often held accountable for all activities. This fits with our sense that teaching institutions have flatter organizational structures than research institutions, certainly in the area of responsibility for research IT services and infrastructure. At such institutions, we surmise, the CIO is so often accountable for research CI activities because other administrative positions whose portfolios might include those activities simply do not exist.

For most of the following discussion, we have dichotomized our data into two categories, CIO and non-CIO. The latter category includes all the other officers whose accountability we asked about.

Figure 5-3 presents data for the four research-related activities for which results varied significantly between research and teaching institutions. Among service activities, accountability for providing research system support services is more widely distributed where research is the primary mission. Whereas nearly 9 in 10 teaching institutions report that the CIO is accountable for providing support services for research systems, slightly fewer than three-quarters of research institutions do. Making up most of the difference at research institutions, individual researchers are accountable in 13.3% of cases, and academic deans are responsible in 7.4%.

Although the magnitude of the difference is greater, a similar pattern holds for accountability for providing ongoing maintenance for systems purchased with one-time research funds. At about three-quarters of teaching institutions the CIO is accountable; at research institutions, just under half report that the CIO is accountable. Making up most of the difference at research institutions, individual researchers are accountable in 27.9% of cases, and academic deans are responsible in 16.3%.

Among research-related infrastructure activities, accountability for providing sufficient storage for research data was significantly associated with institutional mission and follows the same pattern as the other activities depicted in Figure 5-3. At almost 8 in 10 teaching institutions the CIO is accountable, while that is the case at only 6 in 10 research
institutions. Making up most of the difference at research institutions, individual researchers are accountable in 28.7% of cases.

Accountability for providing space and environmental support for research systems owned by campus entities other than central IT is the last of the research-related activities associated significantly with institutional mission. Among teaching institutions, the CIO is accountable at nearly half, with the CAO (18.5%) and individual researchers (11.0%) contributing most to the “other” category. At only a quarter of research institutions is the CIO accountable for this activity. Academic deans are accountable at 35.3% of research institutions; individual researchers and CROs are each accountable at about 11%.

Interesting details are revealed when we look at the full set of responses—not just the dichotomized CIO and “other” responses—for our question about enforcement of the research community’s compliance with national privacy regulations (see Figure 5-4). At about a third of research institutions, the CIO is accountable for this activity, and at another third the CRO is accountable. At these institutions, no other officer was reported accountable by as many as 10% of respondents.

Among teaching institutions, just under a third reported that the CIO was accountable for compliance, closely paralleling the responses at research institutions. But here the CRO was reported accountable by only about a ninth. The CAO makes up the difference, with slightly more than a quarter of teaching institutions reporting that officer as accountable for enforcing compliance. This reinforces our earlier speculation that the CAO position incorporates some CRO duties at many teaching institutions. At teaching institutions, too, academic deans and CFOs are accountable for this activity twice as frequently as at research institutions. The work being done by these officers is very similar, of course; the difference is just a matter of who is doing it.

Authority and Resources

Accountability, authority, and resources form a classical three-legged stool; any two, without the third, results in an unstable structure. We asked our survey respondents to tell us whether the CIO had sufficient authority and resources to meet his/her responsibilities for each of our eight representative research-related activities. Consistently,
agreement that the CIO’s authority was sufficient exceeded the level of agreement that resources were sufficient. In most cases, where the CIO was listed as primarily accountable for an activity, agreement about sufficiency of authority and—a little less frequently—resources was stronger.

A Pattern of Underfunding

Among research-related services (Figure 5-5), mean agreement was relatively good that the CIO had sufficient authority to meet responsibilities for research system support services and security. The means of 3.95 and 3.78, respectively, on our five-point scale are well above “neutral” and just below “agree.” By contrast, agreement about authority for providing ongoing maintenance and support for resources obtained with one-time funding and about enforcing the compliance of the research community with national privacy regulations was closer to “neutral” than to “agree.”

This pattern of agreement about authority roughly corresponds to the results for accountability. In areas where respondents most often said the CIO was held primarily accountable, mean agreement that the CIO has sufficient authority was stronger.

For all research-related service activities, level of agreement that resources were sufficient for the CIO to meet his/her responsibilities was lower than agreement about authority, hovering just above “neutral” for support and security services and between “disagree” and “neutral” for ongoing maintenance and enforcing compliance. These findings reinforce our sense that CIOs perceive research systems as at least a bit of a burden and the cost of their care and feeding an unfunded mandate.

The results are very similar for research-related infrastructure activities (Figure 5-6). Mean agreement that authority to meet responsibilities for research and teaching bandwidth is sufficient falls about halfway between “agree” and “strongly agree.” Agreement about authority to meet responsibilities for providing research data storage is somewhat weaker, but still closer to “agree” than to “neutral.” But respondents give us their lowest levels of agreement among these eight activities for the CIO’s authority for providing space and envi-

Figure 5-4. Accountability for Enforcing Research Community’s Compliance with Privacy Regulations, by Institutional Mission (N = 299)
environmental support for research systems. Here, agreement is just above “neutral.” Agreement about the sufficiency of resources lags behind agreement about authority for each of the four infrastructure activities by more than half a point.

It might be tempting to dismiss these consistent reports of underfunding of research-related activities as so much bellyaching on the part of CIOs. But it is important to note that constraints on funding are, in most academic environments, much stiffer than constraints on authority. An executive leader can often grant (or a CIO can seize) authority more easily than money. Money, as we all know, doesn’t grow on trees, but to some extent authority does. The temptation—and the pressure—to accept authority may trump the CIO’s awareness of budget constraints, leading to an all-too-familiar imbalance between the CIO’s portfolio and budget.

Providing sufficient network bandwidth for research is the only research-related activity we asked about for which agreement about authority was significantly associated with institutional mission (see Table 5-1). While responses averaged above “agree” for both types, research institutions agreed just over a third of a point more strongly, on average, that they had the authority to meet their responsibilities for research bandwidth. This is consistent with the higher priority a research institution puts on that activity. A research institution is more likely to reach consensus that the CIO should “Do whatever it takes” (up to a point, of course) to provide research bandwidth. At a teaching institution, it seems likely that incrementing institutional bandwidth to support research requires more discussion and involves more parties.

Providing research data storage and providing ongoing maintenance for systems obtained with one-time funds were the only infrastructure activities we asked about for which agreement that the CIO has sufficient resources to meet his/her responsibilities was significantly associated with institutional mission (see Table 5-2). In each case, greater mean agreement was reported by teaching institutions. We speculate that at research institutions, demand for these two activities may be greater and may be outstripping resources faster than at teaching institutions.
For all eight activities, agreement about the sufficiency of both authority and resources is significantly positively associated with the central IT organization’s reported effectiveness at integrating our five CI technologies to provide seamless support for research. The greater the agreement that those two factors are sufficient, the more effective central IT’s...
integration of the technologies. (For more associations with central IT’s effectiveness at integrating CI technologies, see Chapter 6.)

Variations in Authority and Resources, by Accountability

At the beginning of this section, we compared accountability, authority, and resources to a three-legged stool. Evaluating the effect of accountability on both authority and resources, we see that for most of our eight activities, the three really are mutually reinforcing. As Table 5-3 shows, when the CIO is the accountable party, the authority and the resources he/she can draw on are more likely to be sufficient.

Similarly, as Table 5-4 shows, when the accountable official is the CIO, agreement is stronger that the CIO has sufficient authority for all our research-related infrastructure activities. Agreement is also stronger that the accountable CIO has sufficient resources to meet responsibilities for providing research data storage and space and environmental support for research systems. Agreement about the sufficiency of resources for the two bandwidth activities was not meaningfully associated with accountability, perhaps reflecting the importance of the network to campus activities in general and the priority its funding receives regardless of who is ultimately accountable for it.

Aids to More Effective Support for CI Technologies

Accountability, authority, and resources all appear to contribute to success in the support of research cyberinfrastructure, but what do CIOs feel they need most in order to meet the demand for research support? Among the near-infinite possibilities, our advisory team helped guide us toward these eight items:

Table 5-3. Agreement That CIO Has Sufficient Authority and Resources for Research-related Service Activities, by Accountable Officer

| Accountable Officer | Authority | | | Resources | |
|---------------------|-----------|---------|----------------|-----------|
|                     | N | Mean Agreement* | Std. Deviation | N | Mean Agreement* | Std. Deviation |
| Providing support services for research systems | | | | | |
| Other official | 53 | 3.32 | 1.034 | 52 | 2.73 | 1.223 |
| CIO | 243 | 4.10 | 0.844 | 241 | 3.22 | 1.129 |
| Total | 296 | 3.96 | 0.929 | 293 | 3.14 | 1.159 |
| Providing research system security | | | | | |
| Other official | 61 | 3.11 | 1.240 | 58 | 2.67 | 1.316 |
| CIO | 226 | 4.03 | 0.864 | 224 | 3.27 | 1.161 |
| Total | 287 | 3.83 | 1.024 | 282 | 3.15 | 1.216 |
| Providing ongoing maintenance for IT resources obtained with one-time funds | | | | | |
| Other official | 107 | 2.53 | 1.184 | 105 | 2.20 | 1.121 |
| CIO | 183 | 3.91 | 1.036 | 181 | 2.93 | 1.195 |
| Total | 290 | 3.40 | 1.277 | 286 | 2.66 | 1.219 |
| Enforcing researchers’ regulatory compliance | | | | | |
| Other official | 177 | 2.92 | 1.130 | 169 | 2.64 | 1.065 |
| CIO | 99 | 3.77 | 1.105 | 101 | 3.02 | 1.200 |
| Total | 276 | 3.22 | 1.191 | 270 | 2.79 | 1.130 |

*Scale: 1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, 5 = strongly agree
increased funding for central IT infrastructure,
- increased funding for central IT services,
- increased communication/outreach between researchers and central IT,
- increased involvement of central IT in developing budgets for grants and contracts,
- an increased share for central IT of indirect cost recovery funds from grants and contracts,
- greater inclusion of researchers in institutional IT governance bodies,
- increased authority for central IT to enforce standards for resource management, and
- increased authority for central IT to enforce standards for resource acquisition.

In our survey, we asked respondents to select the three items from this list that would most help the central IT organization support more effective research use of each of the five CI technologies at their institutions. Figures 5-7 through 5-9 present the percentages of respondents who selected each of the eight items.

### Funding and Communication/Outreach

Figure 5-7 includes the three items from the top of the preceding list, each of which was selected by between about 50% and 70% of respondents. For all five technologies, majorities of respondents selected increased funding for infrastructure and services as an important aid to improving CI support. About this, Patrick Burns, vice president for information technology at Colorado State University, says, “As is the case at many other institutions, sufficient funding for central IT at Colorado State is a preeminent issue. We are continuing to experience dramatic increases in demand for and usage of central IT core services such as

<table>
<thead>
<tr>
<th>Table 5-4. Agreement That CIO Has Sufficient Authority and Resources for Research-related Infrastructure Activities, by Accountable Officer</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Accountable Officer</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>Providing bandwidth for research</strong></td>
</tr>
<tr>
<td>Other official</td>
</tr>
<tr>
<td>CIO</td>
</tr>
<tr>
<td>Total</td>
</tr>
<tr>
<td><strong>Providing bandwidth for teaching and learning</strong></td>
</tr>
<tr>
<td>Other official</td>
</tr>
<tr>
<td>CIO</td>
</tr>
<tr>
<td>Total</td>
</tr>
<tr>
<td><strong>Providing research data storage</strong></td>
</tr>
<tr>
<td>Other official</td>
</tr>
<tr>
<td>CIO</td>
</tr>
<tr>
<td>Total</td>
</tr>
<tr>
<td><strong>Providing space, etc., for research systems</strong></td>
</tr>
<tr>
<td>Other official</td>
</tr>
<tr>
<td>CIO</td>
</tr>
<tr>
<td>Total</td>
</tr>
</tbody>
</table>

*Scale: 1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, 5 = strongly agree
as e-mail, spam filtering, the learning management system, the portal, identity management, IT security, wireless networking, and so on. With the burden these activities impose on my budget, research technologies such as high-performance computing are simply lower priority on my radar screen. Adding them on top of our current operational environment without adequately funding them would be disruptive to the core services everyone here relies on every day."

Rising above the other technologies in the infrastructure funding group are data storage and management and advanced network infrastructure, which were selected by just over 70% of respondents, suggesting that demand for these technologies, in particular, is increasing at a rate that will be difficult to address with current budgets.

For all technologies, again, slim majorities of respondents selected increased funding for central IT services. Here the technology whose funding seemed of most concern was that associated with collaboration within virtual communities. Presumably, CIOs see demand for services in this area outstripping central IT’s resources now or in the near future.

Only our findings for high-performance computing and data storage and management were significantly different for the two institutional missions. For both technologies, research institutions were substantially more likely than teaching institutions to select increased funding for central IT services as an aid to improved research support.

Majorities of respondents said that increased communication/outreach between researchers and central IT would help them provide more effective research support. David Woods, assistant director for research computing at Miami University, reports, “The university purchased its own high-performance computing cluster a little over two years ago, and faculty are still figuring out how to adjust their research programs to take advantage of that type of resource. So for us, at this point, increased communication is probably the most important thing in providing more effective support.”

The standout finding here again is related to resources for collaboration within virtual communities. This is consistent with our finding in Chapter 4 (Table 4-2) that the CIO’s mean ability to obtain information about collaboration resources is poorest for this area among the five CI technologies.
Pairing all the findings for the communication/outreach question with those for the service funding question, the message coming through to us is that central IT wants to help researchers use CI technologies, feels financially strapped by the service demand, and doesn’t really know what researchers want. And this is especially true for collaboration resources.

**Grants and Contracts**

Figure 5-8 includes the two middle items from the list at the beginning of this section. Both items are related to grant funding, and both were selected by between about 20% and 40% of respondents. We offered the first of these items, increased involvement of central IT in developing budgets for grants and contracts, for selection by respondents who felt that the costs of various CI technology support items would be more appropriately, more adequately, and/or more reliably funded as line items in grant budgets than as elements of the institution’s distribution formula for indirect cost recovery funds.

Although those who selected this item very likely had funding in mind, many may also have had authority in mind—that is, some say-so in the choice of IT resources being brought to campus, especially among those to whom it seemed likely that responsibility for the ongoing management of those resources would fall to central IT.

Response rates for increased involvement in budget development were somewhat higher for high-performance computing and CI applications and tools than for other items. We surmise that the impacts on the central IT organization are particularly heavy when grants and contracts bring these two CI technologies to campus. Nevertheless, the responses for the three remaining technologies suggest that at least a quarter of respondents find the support demands of each of them have an impact as well.

The second item, an increased share for central IT of indirect cost recovery funds, was for those who felt that the indirect cost recovery formula simply needed to be adjusted to more fully meet central IT’s support costs for the technologies in question. In reality, this is
more easily said than done, and many of our respondents know that. As Carolyn Gard, senior director for academic technology services at Miami University, reports, “In the last two to three years, I’ve had several conversations with the associate provost for research and dean of the graduate school about allocating a portion of the grant overhead to a replacement fund for the research cluster. Unfortunately, because those funds are already split quite a few ways, they haven’t been able to give IT a share.” Of course, decisions about the division of indirect cost recovery funds are only partly in the hands of the campus administration; they must also meet funding agency requirements. That seriously complicates the issue for CIOs and CROs alike, and it’s one of the reasons many prefer the path of working with faculty to include support for their technology use as line items in their grant budgets.

Among those who selected a greater share of indirect cost recovery funding, high-performance computing stimulated the most responses; resources for collaboration within virtual communities prompted the fewest. Perhaps the contrast derives from the intensity of the support burden the technologies impose on central IT, but it may also have to do with the frequency with which those items are involved in grant activity. As we saw in Chapter 3 (Figure 3-10), high-performance computing is the most important of our CI technologies to science and engineering research, the academic area that attracts the most grant funding at most institutions; collaboration resources are the least important in this academic area.

Similarities between the two groupings in Figure 5-8 might lead one to suspect that respondents are “working both sides of the street,” looking for both line-item funding and increased indirect cost funding for support of CI technologies. In fact, for high-performance computing, of the 64 respondents who selected the line-item approach and the 72 who selected the indirect costs approach, only 26 selected both. Results were similar for the other CI technologies. This suggests that most respondents see these as two separate strategies for improving research support.

Another of the very few significant differences we see between research and teaching institutions in the context of aids to more effective support for CI technologies is related to the perceived value of an increased share of indirect cost recovery funds for central IT. For all technologies except resources for collaboration within virtual communities, two to three times as many research institution respondents selected this item. It seems likely that this finding reflects the very small pools of indirect cost recovery funds available at many teaching institutions.

### Governance and Standards

Relative to the other items on our list of eight, few respondents selected inclusion of researchers in institutional IT governance bodies as helping central IT support more effective research use of CI technologies (see Figure 5-9). As with all eight items, we must bear in mind that greater numbers of respondents might have selected them if we hadn’t limited their selections to three. Nevertheless, we were a bit surprised that the numbers here were so low. More frequent selection of inclusion of researchers in governance activities would have paralleled findings from a forthcoming ECAR study, *Process and Politics: IT Governance in Higher Education*, in which more effective IT governance practices were associated with a greater degree of inclusiveness in the composition of IT advisory groups.

As an example of the benefit of including research faculty in governance, Carol Myers, director, college technology at Paradise Valley Community College, relates the story of the physics department chair at her campus, who participates in summer research projects at the Fermi National Accelerator Laboratory.
“She is also a member of our Technology Coordinating Team, which sets the overall IT strategic plan, also approves capital requests, and gives initial approval for IT security initiatives. Having her involved in some of our IT decisions not only benefits what she is doing with our students here—for example, getting them access to Fermi Lab resources requiring a Kerberos handshake between our resources and theirs—but gives us a broader understanding of how other universities and government agencies are doing their jobs.”

The standout finding in the group concerning inclusion of researchers in IT governance relates to resources for collaboration within virtual communities. This may reflect the general lack of CIO knowledge about this technology that we discuss in Chapter 4 and in the discussion of Figure 5-7, and the respondents’ hope that by including researchers in the governance process more information about researchers’ needs might come to light. This interpretation is strengthened a bit by the relatively low response rate for this question in the context of advanced network infrastructure, the CI technology about which CIOs are most knowledgeable.

Low numbers also selected increased authority for central IT to enforce standards for acquisition and management of resources as helping central IT support more effective research use of CI technologies. These small numbers seem consistent with our findings, reported earlier in this chapter, that respondents tended to rate their authority for most research-related activities significantly higher than their resources, and suggest that CIOs don’t feel additional authority would bring much additional benefit.

With regard to increased authority to enforce standards for resource management, the data storage and management context stimulated the greatest response among our five CI technologies. This may reflect the respondents’ view that the data storage resources central IT is able to provide would stretch further if management standards were adhered to more closely. In this regard, Bo Vieweg, director of the office of information technology at Seattle University, says, “This is not unique to our environment, certainly, but better life-cycle management of data would...
really be helpful to us. Rolling unused data off to an archive server would free up resources for new uses.”

Finally, the more interesting findings in the group concerning increased authority to enforce standards for resource acquisition are the lower percentages—those for advanced network infrastructure and resources for collaboration within virtual communities. As we learned in Chapter 3, these are the CI technologies that central IT most often provides and funds, and it follows that fewer respondents would see a need for greater influence over purchase decisions when most of those decisions are made—or at least coordinated—in house.

**Summary and Implications**

If accountability, authority, and resources make up the three-legged stool that central IT’s support for CI technologies rests on, then our respondents are telling us that in most cases the accountability and authority legs are well matched, but the resources leg is a bit short.

Majorities of respondents identified the CIO as the person the CEO holds accountable for six of the eight research-related activities we asked about. CIOs are least often held accountable for enforcing compliance with privacy regulations and providing space and environmental support for research IT resources owned by campus entities other than central IT but are nevertheless more often accountable for those than any other officer. Not being held accountable for the first of those may seem a boon to some CIOs—policy enforcement is seldom jolly work. But for the majority of CIOs who do not provide space and environmental support for non-central IT resources, the situation is more of a missed opportunity. Hacker and Wheeler suggest that colocating research systems, among other steps, “empower[s] scholarly communities by reducing the amount of effort required to administer, learn, and use resources, which frees the community to take risks, explore, innovate, and perform research.”

Mean agreement that the CIO has sufficient authority for our eight research-related activities is uniformly above “neutral,” and in the cases of providing support services and security for research systems and providing research data storage, the mean approaches “agree.” For providing bandwidth for both research and teaching and learning purposes, mean agreement is well above simple agreement. At institutions where the officer accountable for each of these eight activities is the CIO, mean agreement about sufficient authority is even stronger.

Agreement about the sufficiency of the CIO’s resources for the eight research-related activities is uniformly lower than agreement about authority, supporting our sense that authority is easier to obtain (though perhaps less pleasant to accept) than money. Only for the bandwidth-related activities is agreement relatively high. For providing support services and security for research systems and providing research data storage, it is slightly above or very slightly below “neutral,” whereas for all other activities it is substantially lower.

Supplementing these findings, respondents’ selection of items that would help central IT support more effective research use of CI technologies highlighted deficiencies in resources more often than authority. More than 50% of respondents selected increased funding for central IT infrastructure and central IT services. The only other item selected with this frequency was increased communication/outreach between researchers and central IT. (Central IT seems as interested in greater knowledge and client interaction as it does in money. This is heartening!) Varying somewhat by CI technology, between about 20% and 40% of respondents indicated that two grant-related items would help improve CI support: increased involvement of central IT in developing grant budgets and an increased share for central
IT of indirect cost recovery funds. Whereas the latter is clearly about money, the former is likely about ensuring authority over (or at least timely foreknowledge of) the kinds of resources that grants will introduce into the IT support environment, as well as the availability of money for support.

The items selected least often as being helpful in central IT's support for research were two authority items: increased authority for central IT to enforce standards for resource management and for resource acquisition. We speculate that more respondents would have selected the latter, at least, if they had not had the opportunity to select the broader item, discussed above, about increased involvement of central IT in the development of grant budgets.

Now that we understand something about what is expected of CIOs in terms of CI support and have some insight into the authority and resources CIOs have and feel they need to be more effective, we can move on to the next chapter. There we find connections between these items and the respondents’ sense of their campuses’ collaborative environments, as well as their assessment of the central IT organization’s success at integrating CI technologies in support of research.

Endnotes
6

Pulling Together to Support Research

“Teamwork is the quintessential contradiction of a society grounded in individual achievement.”
—Marvin Weisbord

Key Findings

- Opinion is diverse but, in general, respondents are reserved in their assessments of the degree to which their institutions’ researchers collaborate in the use of CI resources and to which their institutions realize economies of scale.
- Similarly, agreement is weak that effective institutional incentives exist to encourage researchers’ sharing of CI resources and partnering with central IT to achieve economies of scale.
- Agreement that collaborative practices and incentives to collaborate exist is stronger at institutions where central IT provides and funds various combinations of CI technologies, where the CIO is knowledgeable about them, and where inventories of CI resources are more complete.
- Agreement that collaborative practices and incentives to collaborate exist is stronger at institutions where the CIO has sufficient authority and resources to meet his/her responsibilities for providing a variety of support services as well as space and environmental support for CI technologies.
- Respondent agreement about the effectiveness of the central IT organization at integrating CI technologies in support of research is strongly associated with collaborative practices and institutional incentives to encourage them.
- At institutions where more personnel more often use resources for collaboration within virtual communities, central IT’s effectiveness at integrating CI resources is significantly greater. This was true for the level of use of no other CI technology.
- The involvement of central IT in providing space and environmental support for research IT systems owned by other campus entities may have utility as an indicator of an institution that excels in research CI support.

Because research in higher education has traditionally been grounded in individual achievement, it was natural for CI technologies to emerge independently in several places on a given campus. Each of the five CI technologies this study addresses tells this story in a slightly different way.

High-performance computing resources.
At a few of the most successful research universities, central IT acquired early supercomputers and provided access to them. But as research computing capacity became available using lower-priced, highly flexible clusters of commodity processors, high-per-
formance computing became more generally available, not just at more institutions, but under more diverse control within institutions. Where high-performance computing cycles were obtained by researchers from off-campus sources—NSF supercomputer centers, for example—their use tended to be project-, researcher-, or lab-specific, and not part of an integrated institutional research enterprise IT environment. Some institutions provided effective centralized support services for researchers using off-campus facilities, but many did not. Acquisition of visualization systems—the Cave Automated Virtual Environment, for example—also often followed the grant-funded, grantee-controlled path into higher education research use.

CI applications and tools. Commercial statistical and mathematical research applications such as SPSS and Mathematica are often site-licensed by the central IT organization and made available to researchers, but these are the exception; much of the software used for research in science and engineering is open source, and its adoption tends to be lab by lab or discipline by discipline, on the basis of individual research needs.

Data storage and management resources. Data storage capacity and tools for managing massive data sets have, until recently, also been the province of individual researchers. Among other factors, recent changes in funding agencies’ requirements for grant-related data management practices have motivated some researchers to consider using central IT data facilities and services.

Advanced network infrastructure resources. Access to high-performance networks such as Internet2 and National LambdaRail has generally been a well-coordinated institutional activity, in part because the investment tends to be in the multimillion-dollar range, in part because the benefit of such networks goes far beyond the individual research lab, and in part because grant programs to fund broad campus infrastructure improvements have been rare. As a result, networking has been one of the few technologies consolidating the research IT environment rather than fragmenting it.

Resources for collaboration within virtual communities. Like visualization systems, resources in support of collaboration developed in a researcher-specific way. The Access Grid, which emerged from Argonne National Laboratory’s Futures Laboratory in the late 1990s, was an early network-based tool for collaboration. At some institutions it was deployed as a central resource, but at others its deployment and use were more researcher specific. Follow-on systems show similar patterns of use, being shared among campus units where central IT support resources are available, and used in a more proprietary way where the researcher/owner provides support.

From this background, it is clear that CI technologies have developed in a highly distributed way. Where their use is infrequent and by small numbers of institutional personnel and where their expansion is neither planned nor expected, this model may remain effective. Where the use of CI resources has outgrown this model or is likely to, though, good management practice calls for at least a degree of centralization. Thomas Hacker and Bradley Wheeler argue persuasively for this, summing up the case by stating, “By working together rather than independently, the university community has the best chance of creating a working and sustainable infrastructure and support model for research computing.”1

The respondents to our survey told us how their institutions measure up with regard to four collaborative practices as well as how effectively their central IT organizations integrate the five CI technologies we explored in our survey to provide seamless support for research. In this chapter we discuss those responses, their significance, and their implications.
Collaboration

To inquire about collaborative activities, we asked for respondents’ level of agreement with four statements, each getting at collaboration from a slightly different angle. We asked first whether

- researchers generally collaborate in the use of CI resources and
- whether the institution realizes economies of scale in the use of CI resources.

We refer to these as “collaborative practice” items below, but we appreciate that they are both, in different ways, about efficiency as well.

In addition, we asked for respondents’ agreement that effective institutional incentives existed for researchers to

- share CI resources with other campus researchers and
- partner with central IT to achieve economies of scale in the use of CI resources.

We refer to these as “incentives to collaborative practice” below, but again include “efficient practice” as part of that.

As seen in Figures 6-1 through 6-4 below, responses to each of the four statements followed a normal, bell-shaped distribution, indicating considerable variability around a core of neutral responses; the latter averaged a third of the total. Mean levels of agreement with each statement appear in Table 6-1. All but one are below “neutral,” suggesting generally lackluster-performance in the areas of collaboration, the achievement of economies of scale, and the efficiencies associated with both.

Collaborative Practice

Research IT resources can be very expensive, and although those resources may be essential for achieving a given research goal, their use by a single researcher may leave a great deal of their capacity unused. The learning curve for using CI resources effectively may be as steep as the financial cost. In both of these areas—and others, no doubt—there is opportunity for researchers to collaborate. A researcher whose grant was generously funded might provide access to an expensive device acquired with grant funds to a fellow researcher who was less fortunate. Or a researcher who has mastered the use of a complex resource may spend time teaching another what he has learned. Practices such as these are symptomatic of a collaborative environment that helps stretch scarce research dollars and can lead to the development of synergistic communities of scholars whose contributions to their disciplines exceed the sum of their individual efforts.

Collaborating in the Use of CI Resources

Just under a third of respondents agreed or strongly agreed that researchers at their institutions generally collaborated in the use

<table>
<thead>
<tr>
<th>Statement</th>
<th>N</th>
<th>Mean Agreement*</th>
<th>Std. Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Researchers generally collaborate in the use of CI resources.</td>
<td>304</td>
<td>3.03</td>
<td>0.947</td>
</tr>
<tr>
<td>Institution realizes economies of scale in the use of CI resources.</td>
<td>306</td>
<td>2.78</td>
<td>0.978</td>
</tr>
<tr>
<td>Incentives exist for researchers to share CI resources with other campus researchers.</td>
<td>310</td>
<td>2.69</td>
<td>1.011</td>
</tr>
<tr>
<td>Incentives exist for researchers to partner with central IT for economies of scale.</td>
<td>326</td>
<td>2.93</td>
<td>1.092</td>
</tr>
</tbody>
</table>

*Scale: 1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, 5 = strongly agree
of CI resources, whereas just over a quarter disagreed or strongly disagreed (see Figure 6-1). Of the four collaboration questions we asked, respondents were most often neutral about this one, perhaps suggesting that many of them lacked confidence in their knowledge about researchers’ collaborative activities. Mean agreement (see Table 6-1) was essentially neutral: 3.03 on our five-point scale.

Agreement that researchers generally collaborate in the use of CI resources was significantly, but not strongly, associated with institutional mission. At research institutions, mean agreement was 3.22 on that question’s five-point scale, whereas at teaching institutions the mean was 2.87. This may reflect the generally smaller volume of research activity that characterizes teaching institutions; fewer or less-active researchers might result in fewer opportunities for the kind of on-campus collaboration we asked about. Agreement was also significantly associated with the presence on campus of a research IT advisory body and a unit in central IT dedicated to research support.

Stronger, more significant associations exist between responses about collaboration and the extent to which researchers obtain access to various CI technologies from central IT and the extent to which central IT is a funding source for the technology. In particular, where the central IT organization is both provider and funding source for high-performance computing resources and CI applications and tools, and where it is the funding source for advanced network infrastructure, respondents were more likely to agree that researchers generally collaborate in the use of CI resources.

For high-performance computing, CI applications and tools, and resources for collaboration, we found greater agreement that researchers generally collaborate where the CIO’s overall knowledge about the technology was greater. And for all CI technologies we found that where the institution’s inventory of resources related to these technologies was more complete, agreement about collaboration was greater. These findings combine with those reported immediately above to suggest that the degree of the CIO’s engagement in and “sponsorship” (providing and funding) of CI technologies creates an environment in which researchers tend to collaborate. As with all our findings, though, it is not possible to say with assurance which factors are causes and which are effects.
The level of knowledge about CI technologies attributed to other officers, as well, was often positively associated with agreement that researchers generally collaborate. In particular, higher levels of knowledge about high-performance computing, CI applications and tools, data storage and management, and resources for collaboration were all associated with higher levels of agreement that researchers collaborate. This was true for all four officers: the chief academic officer (CAO), the chief research officer (CRO), deans in science and engineering, and other deans (excepting only the CRO’s knowledge about advanced network infrastructure).

**Realizing Economies of Scale**

Agreement that the institution realizes economies of scale in the research use of CI resources was weaker (see Figure 6-2). Nearly 4 in 10 respondents disagreed or strongly disagreed that the institution realizes economies of scale in the research use of CI resources, whereas just under a quarter agreed at some level. The mean response of 2.78 (see Table 6-1), well below neutral, was the lowest for any of our four collaboration questions, suggesting either that achieving economies is not a widespread goal or that if it is a goal, it is difficult to achieve.

As with agreement that researchers generally collaborate, we found agreement that the institution realizes economies of scale was associated with institutional mission. At research institutions, mean agreement was 2.98 (“neutral”) on the five-point scale, whereas at teaching institutions the mean was a third of a point lower, at 2.64. Agreement here, as well, was also significantly associated with the presence on campus of a research IT advisory body and a unit in central IT dedicated to research support.

Here again, strong associations exist between agreement about the realization of economies of scale and the extent to which central IT is a provider of and funding source for high-performance computing, CI applications and tools, and—more significantly than for the previous question—data storage and management resources. Unlike the previous case, here central IT as a funding source for advanced network infrastructure resources was not associated with the economies of scale question, possibly because central IT is so uniformly the funding source for that technology.

Also paralleling the findings for researcher collaboration, the CIO’s knowledge about high-performance computing and CI applications and tools and the status of the institution’s inventories of all CI technologies were significantly associated with agreement about the institution’s realization of economies of scale. Also positively associated with agreement here was the level of knowledge of the CAO and CRO about CI applications and tools and data storage and management, and of science and engineering deans about data storage and management and advanced network infrastructure resources.

For this question, as for the last, we cannot be sure whether level of agreement with the question’s premise is the cause or the result of the associated findings. We can say with some confidence, though, that central IT’s involvement in providing and funding high-performance computing, CI applications and tools, and data storage and management, plus the knowledge of the CIO and other officials about certain technologies do in some way go hand in hand with realizing economies of scale.

Sufficiency of authority and resources, dealt with in Chapter 5, was not associated with most collaborative practice items. Of all the sufficiency of authority items, only one, about the CIO’s authority to provide space and environmental support for research IT resources owned by campus entities other than central IT, was significantly associated with respondents’ agreement about the two collaborative practice
items discussed above. We will revisit this finding as its place in a broader pattern emerges in the following sections.

**Incentives to Collaborative Practices**

Here we look at whether institutional-level incentives exist for one kind of collaboration, researchers sharing CI resources with other researchers on campus, and one mechanism for achieving economies of scale, researchers partnering with central IT. Consideration of these findings may bring us a little closer to understanding the findings discussed above.

**Incentives for Researchers to Share Resources**

On the whole, respondents were less inclined to agree that incentives exist for researchers to share CI resources (Figure 6-3) than that they generally collaborate (Figure 6-1; Table 6-1). This may suggest that researchers collaborate by sharing resources with others on campus to a greater extent than the institution encourages them to, and/or that sharing resources with others on campus was only one kind of collaboration in respondents’ minds as they responded to our survey and that they felt the institution offered few incentives for the other kinds.

Responses to this question were not significantly associated with institutional mission. Agreement was positively associated with the presence of a dedicated research support unit within central IT but was not associated with the presence of a research IT advisory body.

Level of agreement was positively associated with central IT as the provider and the funding source for high-performance computing resources, CI applications and tools, and data storage and management resources. Agreement was also positively associated with the CIO’s overall knowledge of high-performance computing and CI applications and tools, and with the completeness of inventories for all CI technologies except advanced network infrastructure. And it was positively associated with the CAO’s, the CRO’s, and the science and engineering deans’ levels of knowledge about high-performance computing, CI applications and tools, and data storage and management resources.

Although responses here are not associated with the CIO’s accountability for any of the eight service and infrastructure activities we asked about (see Chapter 5), they were positively
associated with agreement about the sufficiency of the CIO’s authority and resources to meet responsibilities for several research-related service and infrastructure activities. Table 6-2 summarizes the authority and resources associations for this set of incentives as well as the set of incentives we will consider next. (For full statistical details, see Appendix D.)

Six of the eight research-related activities were included in the cluster of associations with authority; only providing bandwidth for research and for teaching and learning fell below our threshold of significance. In the cluster of associations with resources, significant associations exist with all activities except providing ongoing maintenance of resources obtained with one-time funds and the two bandwidth activities.

Taking a step back and looking broadly at our findings for the researcher sharing incentive, it appears that respondents more often, on average, perceive the institution to have effective incentives in place where CIOs are able to take some of the burden from researchers by providing support services for research IT systems such as system administration, identity management, and a help desk; by providing security for research systems, along with ongoing maintenance and support for them when they’re obtained with one-time funds (even without dedicated resources to do so); and by providing space with appropriate environmental controls for them. The presence of a dedicated research IT support unit within central IT also seems to support this perception.

Although we did not ask this explicitly, it seems likely that these forms of assistance from the central IT organization are among the incentives to sharing resources with other researchers that our respondents (mostly CIOs) had in mind as they responded to the survey. Behind this, the researchers may be reasoning that if central IT is willing to take responsibility for some of the headaches that sharing IT resources brings, they are more likely (or more able) to open up the systems they acquire to use by other researchers.

Strengthening the CIO’s ability (authority and resources) to carry out infrastructure and service activities like those listed in Table 6-1 appears to us to be a proactive measure that the research-focused institution should consider if its goal is to encourage researchers to collaborate with other campus researchers and gain the efficiencies that follow.
<table>
<thead>
<tr>
<th>Service Activities</th>
<th>Mean Agreement That Institutional Incentives Exist for Researchers to Share Resources*</th>
<th>Mean Agreement That Institutional Incentives Exist for Researchers to Partner with Central IT*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Authority</td>
<td>Resources</td>
</tr>
<tr>
<td>Support services for research systems</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Disagree</td>
<td>2.27</td>
<td>2.46</td>
</tr>
<tr>
<td>Neutral</td>
<td>2.53</td>
<td>2.63</td>
</tr>
<tr>
<td>Agree</td>
<td>2.79</td>
<td>2.92</td>
</tr>
<tr>
<td>Total</td>
<td>2.70</td>
<td>2.69</td>
</tr>
<tr>
<td>Research system security</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Disagree</td>
<td>2.27</td>
<td>2.38</td>
</tr>
<tr>
<td>Neutral</td>
<td>2.28</td>
<td>2.67</td>
</tr>
<tr>
<td>Agree</td>
<td>2.91</td>
<td>2.98</td>
</tr>
<tr>
<td>Total</td>
<td>2.71</td>
<td>2.70</td>
</tr>
<tr>
<td>Ongoing maintenance of non-central research resources</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Disagree</td>
<td>2.39</td>
<td></td>
</tr>
<tr>
<td>Neutral</td>
<td>2.91</td>
<td></td>
</tr>
<tr>
<td>Agree</td>
<td>2.89</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>2.73</td>
<td></td>
</tr>
<tr>
<td>Enforcing regulatory compliance</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Disagree</td>
<td>2.51</td>
<td>2.48</td>
</tr>
<tr>
<td>Neutral</td>
<td>2.53</td>
<td>2.65</td>
</tr>
<tr>
<td>Agree</td>
<td>2.96</td>
<td>2.99</td>
</tr>
<tr>
<td>Total</td>
<td>2.71</td>
<td>2.67</td>
</tr>
<tr>
<td>Infrastructure Activities</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bandwidth for research</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Disagree</td>
<td></td>
<td>No significant association</td>
</tr>
<tr>
<td>Neutral</td>
<td></td>
<td>No significant association</td>
</tr>
<tr>
<td>Agree</td>
<td></td>
<td>No significant association</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>No significant association</td>
</tr>
<tr>
<td>Bandwidth for teaching and learning</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Disagree</td>
<td></td>
<td>No significant association</td>
</tr>
<tr>
<td>Neutral</td>
<td></td>
<td>No significant association</td>
</tr>
<tr>
<td>Agree</td>
<td></td>
<td>No significant association</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>No significant association</td>
</tr>
<tr>
<td>Storage for research data</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Disagree</td>
<td>2.31</td>
<td>2.52</td>
</tr>
<tr>
<td>Neutral</td>
<td>2.45</td>
<td>2.58</td>
</tr>
<tr>
<td>Agree</td>
<td>2.85</td>
<td>2.94</td>
</tr>
<tr>
<td>Total</td>
<td>2.72</td>
<td>2.70</td>
</tr>
<tr>
<td>Space and environmental support</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Disagree</td>
<td>2.33</td>
<td>2.46</td>
</tr>
<tr>
<td>Neutral</td>
<td>2.90</td>
<td>2.84</td>
</tr>
<tr>
<td>Agree</td>
<td>2.84</td>
<td>3.06</td>
</tr>
<tr>
<td>Total</td>
<td>2.68</td>
<td>2.68</td>
</tr>
</tbody>
</table>

*Scale: 1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, 5 = strongly agree
**Incentives for Researchers to Partner with Central IT**

Respondents were more positive about the existence of institutional incentives for researchers to partner with central IT to achieve economies of scale in the use of CI resources (see Figure 6-4). Their mean agreement was 2.93 on our five-point scale, just below “neutral,” a relatively high figure compared with the mean agreement of 2.69 about incentives for researchers to share CI resources.

As with responses to our question about incentives for researchers to share resources with other campus researchers, responses to this question were not significantly associated with institutional mission. On the other hand, agreement was significantly associated with the presence on campus of a research IT advisory body and a unit in central IT dedicated to research support.

Looking at the extent to which central IT was reported as being the provider and funding source for high-performance computing resources, CI applications and tools, and data storage and management resources, we found stronger association with the question about incentives to partner with central IT than with the question about incentives to share resources.

Agreement about this incentive is significantly associated with the CIO’s overall knowledge about the research use of high-performance computing, CI applications and tools, and data storage and management resources. It is also associated with the status of inventories for all our CI technologies except advanced network infrastructure and with the level of knowledge of the CAO, the CRO, and science and engineering deans about high-performance computing, CI applications and tools, and data storage and management resources.

Among the eight accountability items, agreement that incentives exist to encourage partnering with central IT is stronger only where the CIO is the officer held accountable for providing support services for research IT systems (see Table 6-3). And as Table 6-2 shows, agreement about that incentive is also positively associated with the respondent’s agreement that the CIO has sufficient authority for all service and infrastructure activities except providing bandwidth for research and for teaching and learning, and with the respondent’s agreement that the CIO has sufficient resources for all activities.

Taking a broad view of our findings for the incentive to partner with central IT, we see that respondents agree more strongly, on average, that effective incentives for such partnering are present at institutions where:

- central IT is the provider and funding source of several CI technologies,
- central IT has a dedicated research IT support unit,
- the CIO is knowledgeable about CI technologies, and
- the CIO has the authority and the resources to meet his/her responsibilities for all of the research-related service activities and several of the infrastructure activities we asked about.

As was the case with incentives for researchers to share resources with other campus researchers, we did not ask explicitly what incentives to partnering with central IT our respondents had in mind. Again, though, it seems likely that the infrastructure and services the central IT organization can offer might be among the incentives that our respondents said were in place. Certainly the CIO’s ability to provide space and environmental support for researchers’ IT resources, research system support services, and ongoing maintenance and support for grant-purchased resources should make central IT an attractive partner for many researchers.

When asked specifically what incentives his institution provided for researchers to partner with the central IT organization to
achieve economies of scale, Ilee Rhimes, CIO and vice provost for information technology services at the University of Southern California (USC), pointed to the enthusiastic reception USC’s high-performance computing “condominium” facility has gotten from researchers. “The fact that USC made the kind of investment it did in its data center, its high-performance computing center, and its colocation facilities should be a clear indicator to the campus community that we’re looking at research support from an enterprise perspective. Researchers can put their processor nodes into the high-performance computing facility, and there is no overhead charge; they get the benefit not just of the air conditioning and physical security but of a whole spectrum of infrastructure and support services that are needed for high-performance computing.”

In another example, this one from the University of Victoria, a substantially smaller Canadian research institution, CIO Mark Roman says, “We’re unique in Canada in having a centralized research computing facility. At most Canadian universities, the researcher gets the grant and builds their own room for the data center. Here, we put those resources into a single data center and provide shared storage and support services like system administration, security, and disaster recovery.” This approach has been very successful. In fact, Roman says, “We’re bursting at the seams. Right now we’re building a new $5M data center to be almost entirely populated by research computing. The great thing is that the researchers are working together to solve problems. Just the other day we engaged them in a conversation about storage area networks, and they drove

Table 6-3. Agreement That Effective Institutional Incentives Exist to Encourage Researchers to Partner with Central IT for Economies of Scale, by Officer Accountable for Support Services for Research Systems

<table>
<thead>
<tr>
<th>Accountable Officer</th>
<th>N</th>
<th>Mean Agreement*</th>
<th>Std. Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Other official</td>
<td>54</td>
<td>2.50</td>
<td>1.194</td>
</tr>
<tr>
<td>CIO</td>
<td>234</td>
<td>3.05</td>
<td>1.063</td>
</tr>
<tr>
<td>Total</td>
<td>288</td>
<td>2.95</td>
<td>1.108</td>
</tr>
</tbody>
</table>

*Scale: 1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, 5 = strongly agree
the conversation! They’re glad to participate because they realize that a central service is more effective in meeting their needs.”

Taken as a whole, all of the findings in this section suggest that where a greater level of sharing of resources among researchers is a goal, and/or where achieving economies of scale through partnerships between researchers and central IT is a goal, it may be useful for the institution to ensure that the central IT organization has the political and financial underpinnings it needs to participate meaningfully.

Integrating Cyberinfrastructure Resources

In 2005, San Diego Supercomputer Center Director Fran Berman said about cyberinfrastructure, “[It is] the coordinated aggregate of software, hardware, and other technologies, as well as human expertise, required to support current and future discoveries in science and engineering. The challenge of cyberinfrastructure is to integrate relevant and often disparate resources to provide a useful, usable, and enabling framework for research and discovery characterized by broad access and ‘end-to-end’ coordination.”

The capstone question in our 2008 survey of CI resources and practices asked respondents to tell us how well they were meeting the challenge of integrating CI resources. The exact wording of our question was “Rate your central IT organization’s effectiveness at integrating the resources we have explored in this survey to provide seamless support for research.” To clarify, we added the following paraphrase of an earlier statement by Berman: “‘Integrating’ means bringing together into a seamless whole a wide variety of human, software, and hardware systems to form a platform for enabling activities in research and in teaching and learning. It involves coordination, synthesis, and teamwork.”

The responses showed a reasonably bell-shaped distribution, though it was skewed somewhat toward the negative (“not effective”) extreme (see Figure 6-5). The mean response on our five-point scale was a noticeably low 2.64, midway between slightly and moderately effective.

Demographics

We found no significant associations between these findings and any of our standard demographics, including institutional mission. Effectiveness at integrating CI resources was, however, associated with two of the more subtle institutional characteristics our survey addressed. These are presence of a distinct unit in the central IT organization whose explicit mission is to support faculty, clinicians, or other researchers with their research needs, and the presence of a governance/advisory body that deals primarily with IT issues related to research (see Table 6-4).

At institutions where a research support unit existed within central IT, mean effectiveness at integrating CI resources was “moderately effective”; where no such unit existed, mean effectiveness was half a point lower. Specialized central IT support for the research mission would seem to be particularly helpful in integrating CI technologies. It is a venue for the kind of communication and outreach that many respondents said would help them improve research support services (see Figure 5-7) and, as such, we expected a greater difference here. One explanation might be that established work patterns can be difficult to change. As David Woods, assistant director for research computing at Miami University, observes, “Before our research computing group was created, established researchers knew they were basically on their own, and they had adapted their research programs to fit what they could support with their own resources. Over the past couple years we’ve been in place, we haven’t made significant inroads among them, largely, I think, because it takes time to adapt a research program to take advantage of new resources. So that group is
one area where we’re ramping up our communications and hoping to add value. Newer faculty with substantial research programs are typically coming from places where there is a history of more central support, and those researchers are more receptive to using the services of our group.”

The presence of a governance/advisory body that deals primarily with IT issues related to research was associated with an even greater difference in central IT’s effectiveness at integrating CI resources. At institutions reporting such a body, mean effectiveness was slightly better than “moderately effective”; where no such body existed, mean effectiveness was halfway between “slightly effective” and “moderately effective.”

Existence of both of these characteristics suggests an institution that takes coordination of the practical and governance aspects of research seriously, and it stands to reason
that such an institution’s central IT organization would be more effective than others at mounting seamless support services for the research use of CI technologies.

Usage, Provider, and Funding Source

We found that central IT’s effectiveness at integrating CI resources was significantly associated with the level of the institution’s use of only one CI technology: resources for collaboration within virtual communities (see Table 6-5). Where more personnel used those resources more often, the reported level of effectiveness was substantially higher. Perhaps effective CI integration enables and thus increases the use of these technologies; perhaps institutions where virtual collaborations are common are somehow better able to convey the importance of CI technology integration to their central IT organizations. We cannot be sure. Whatever the explanation, the usage level of no other CI technology is associated with effective integration.

One might anticipate that central IT could integrate CI technologies more effectively if it funded and provided access to them, and our findings bear this out. Reported effectiveness increases with the extent to which central IT is the entity from which researchers obtain access to high-performance computing resources, CI applications and tools, and data storage and management resources, and to which central IT funds those technologies.

Campus Officials’ CI Knowledge and Status of CI Inventories

Effectiveness of CI resource integration was also strongly positively associated with the CIO’s overall knowledge about all five of the CI technologies except advanced network infrastructure. Table 6-6 summarizes these associations (and others). (For full statistical details, see Appendix D.) From the connection between the CIO’s knowledge about the use of CI technologies and the effectiveness of central IT’s integration of them, it appears that communication between the CIO, the central IT research support staff, and the researchers themselves may be a key to successful research support. Probably because the CIO’s reported level of knowledge about advanced network infrastructure was uniformly high, no significant association with effectiveness of integration of CI technologies emerged.

Effectiveness at integrating CI resources was also positively associated with the level of knowledge of certain other campus administrators for all five CI technologies. These associations are summarized as well in Table 6-6, with full details in Appendix D. Blank cells in Table 6-6 indicate areas in which effectiveness of central IT’s integration of CI technologies varied independently from the officers’ level of knowledge. For example, in the case of science and engineering deans, those officials’ reported level of knowledge about high-performance computing was not predictive of central IT’s effectiveness. We can only speculate as to the reasons why this might be true, but one possible explanation is that science and engineering deans were reported to be so uniformly knowledgeable about high-performance computing (shown in Figure 4-6) that there simply aren’t enough poorly informed deans to associate proportionately with the many institutions whose reported ineffectiveness at integrating CI resources is relatively low.

As with the CIO’s level of knowledge, the significant associations here lead us to surmise that a CI technologies communication loop that includes other executives, particularly the CAO, is at least symptomatic of—but may also contribute to—better central IT integration of those technologies in support of research.

The more complete the institutions’ inventories of all CI technologies except advanced network infrastructure, the more effective
our respondents’ central IT organizations were reported to be in integrating them in support of research. Mean effectiveness was 0.7 to 0.8 points higher on a 3-point scale where the inventory was complete as opposed to where there was no inventory. A good inventory could result from or contribute to effective integration, or both; in any case, the two things clearly go hand in hand.

**Associations with Accountability, Authority, and Resources**

Associations between effectiveness at integration of CI technologies and accountability for our eight research-related infrastructure and service activities were few, relatively weak, and of marginal statistical significance. At institutions where the CIO was accountable for support services for research IT systems and for providing sufficient bandwidth for research and for teaching and learning, the mean effectiveness of central IT’s integration of CI resources was about half a point higher on our five-point scale than when another officer was reported as accountable. Associations for none of the other activities met our significance standards. Our inference is that the role of the officer accountable for these particular activities is not a key factor in the central IT organization’s success at integrating CI resources in support of research.

On the other hand, we did find strong positive associations between reported effectiveness of the institution’s central IT organization at integrating CI resources and the sufficiency of the CIO’s authority and resources to meet responsibilities for all eight research-related infrastructure and service activities. For each item, respondents who agreed or strongly agreed that their CIO has sufficient authority and resources reported greater effectiveness at integrating CI resources. Among these associations, the highest mean level of effectiveness reported was 3.15 (just above moderately effective); this was among those who agreed or strongly agreed that the CIO has sufficient resources to meet responsibilities for providing space and environmental support for research IT resources owned by campus entities other than central IT. Other effectiveness means among those who agreed or strongly agreed about sufficiency of the CIO’s authority and resources were between 2.69 and 2.92 for authority and between 2.76 and 2.95 for resources. Although these are not high numbers (all but one are below moderately effective), for authority they range from one-half to almost a full point higher than those for respondents who disagree or strongly disagree that the CIO has sufficient authority or resources.

<table>
<thead>
<tr>
<th>Level of Use</th>
<th>N</th>
<th>Mean Effectiveness*</th>
<th>Std. Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Not used</td>
<td>100</td>
<td>2.34</td>
<td>0.956</td>
</tr>
<tr>
<td>Used occasionally by a few personnel</td>
<td>143</td>
<td>2.64</td>
<td>0.915</td>
</tr>
<tr>
<td>Used occasionally by many personnel</td>
<td>29</td>
<td>2.72</td>
<td>0.797</td>
</tr>
<tr>
<td>Used often by a few personnel</td>
<td>34</td>
<td>2.94</td>
<td>0.886</td>
</tr>
<tr>
<td>Used often by many personnel</td>
<td>18</td>
<td>3.56</td>
<td>0.922</td>
</tr>
<tr>
<td>Total</td>
<td>324</td>
<td>2.64</td>
<td>0.955</td>
</tr>
</tbody>
</table>

*Scale: 1 = not effective, 2 = slightly effective, 3 = moderately effective, 4 = very effective, 5 = extremely effective
Finally, we found that reported effectiveness at integrating CI resources was significantly greater among those whose level of agreement about collaborative practices and incentives to collaboration was higher. As Table 6-7 shows, mean responses of “very effective” (4.00) or near it are associated with respondents who strongly agree on three of these items: that researchers generally collaborate in the use of CI resources, that effective institutional incentives exist for researchers to share CI resources with other campus researchers, and that effective institutional incentives also exist for researchers to partner with central IT to achieve economies of scale in the use of CI resources.

Table 6-6. Effectiveness at Integrating CI Resources, by Overall Knowledge of the Technologies

<table>
<thead>
<tr>
<th>Knowledge</th>
<th>Effectiveness*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Chief</td>
</tr>
<tr>
<td></td>
<td>Information Officer</td>
</tr>
<tr>
<td>High-performance computing</td>
<td></td>
</tr>
<tr>
<td>Poor/fair</td>
<td>1.98</td>
</tr>
<tr>
<td>Good</td>
<td>2.66</td>
</tr>
<tr>
<td>Very good/excellent</td>
<td>3.15</td>
</tr>
<tr>
<td>Total</td>
<td>2.71</td>
</tr>
<tr>
<td>CI applications and tools</td>
<td></td>
</tr>
<tr>
<td>Poor/fair</td>
<td>2.09</td>
</tr>
<tr>
<td>Good</td>
<td>2.84</td>
</tr>
<tr>
<td>Very good/excellent</td>
<td>3.13</td>
</tr>
<tr>
<td>Total</td>
<td>2.63</td>
</tr>
<tr>
<td>Data storage and management</td>
<td></td>
</tr>
<tr>
<td>Poor/fair</td>
<td>2.24</td>
</tr>
<tr>
<td>Good</td>
<td>2.56</td>
</tr>
<tr>
<td>Very good/excellent</td>
<td>3.08</td>
</tr>
<tr>
<td>Total</td>
<td>2.66</td>
</tr>
<tr>
<td>Advanced network infrastructure</td>
<td></td>
</tr>
<tr>
<td>Poor/fair</td>
<td>No significant association</td>
</tr>
<tr>
<td>Good</td>
<td>No significant association</td>
</tr>
<tr>
<td>Very good/excellent</td>
<td>No significant association</td>
</tr>
<tr>
<td>Total</td>
<td>2.72</td>
</tr>
<tr>
<td>Collaboration within virtual communities</td>
<td></td>
</tr>
<tr>
<td>Poor/fair</td>
<td>2.35</td>
</tr>
<tr>
<td>Good</td>
<td>2.84</td>
</tr>
<tr>
<td>Very good/excellent</td>
<td>3.12</td>
</tr>
<tr>
<td>Total</td>
<td>2.77</td>
</tr>
</tbody>
</table>

*Scale: 1 = not effective, 2 = slightly effective, 3 = moderately effective, 4 = very effective, 5 = extremely effective
Successful efforts at integrating resources by providing incentives to partner with central IT are not cheap, but some institutions find the benefits attractive enough to overcome long-standing infrastructure obstacles in their pursuit. At Indiana University, Craig Stewart, director, research and academic computing, reports, “We’re really solving two sets of problems by building a new, hardened data center in Bloomington. We haven’t been as proactive as we’d have liked in providing ‘virtual machine’ or ‘condominium’ resources for the research community because we’ve been constrained by electrical power. The supply to our existing data center just wouldn’t permit it. And by aggregating equipment owned by departments in the same facility as equipment purchased by the central IT organization, we can enable analyses of larger scale than would otherwise be possible. Even distributed across campus, as well as between campuses, large parallel runs involving thousands of processors lose considerable efficiency due to latency in fiber optics. The new data center will be well worth the cost because of these considerations and because it will provide secure, managed space for campus computation and storage facilities.”

<table>
<thead>
<tr>
<th>Statements about Practices and Incentives</th>
<th>N</th>
<th>Mean Effectiveness*</th>
<th>Std. Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Researchers generally collaborate in the use of CI resources.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Strongly disagree/disagree</td>
<td>76</td>
<td>2.18</td>
<td>0.844</td>
</tr>
<tr>
<td>Neutral</td>
<td>113</td>
<td>2.71</td>
<td>0.873</td>
</tr>
<tr>
<td>Agree/strongly agree</td>
<td>97</td>
<td>2.98</td>
<td>0.957</td>
</tr>
<tr>
<td>Total</td>
<td>286</td>
<td>2.66</td>
<td>0.944</td>
</tr>
<tr>
<td>Institution realizes significant economies of scale in the research use of CI resources.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Strongly disagree/disagree</td>
<td>118</td>
<td>2.18</td>
<td>0.864</td>
</tr>
<tr>
<td>Neutral</td>
<td>98</td>
<td>2.73</td>
<td>0.807</td>
</tr>
<tr>
<td>Agree/strongly agree</td>
<td>72</td>
<td>3.22</td>
<td>0.876</td>
</tr>
<tr>
<td>Total</td>
<td>288</td>
<td>2.63</td>
<td>0.943</td>
</tr>
<tr>
<td>Effective incentives exist for researchers to share CI resources with others.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Strongly disagree/disagree</td>
<td>129</td>
<td>2.29</td>
<td>0.894</td>
</tr>
<tr>
<td>Neutral</td>
<td>96</td>
<td>2.70</td>
<td>0.872</td>
</tr>
<tr>
<td>Agree/strongly agree</td>
<td>67</td>
<td>3.22</td>
<td>0.867</td>
</tr>
<tr>
<td>Total</td>
<td>292</td>
<td>2.64</td>
<td>0.952</td>
</tr>
<tr>
<td>Effective incentives exist for researchers to partner with central IT to achieve economies of scale in the use of CI resources.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Strongly disagree/disagree</td>
<td>112</td>
<td>2.13</td>
<td>0.871</td>
</tr>
<tr>
<td>Neutral</td>
<td>86</td>
<td>2.67</td>
<td>0.818</td>
</tr>
<tr>
<td>Agree/strongly agree</td>
<td>111</td>
<td>3.14</td>
<td>0.837</td>
</tr>
<tr>
<td>Total</td>
<td>309</td>
<td>2.64</td>
<td>0.945</td>
</tr>
</tbody>
</table>

*Scale: 1 = not effective, 2 = slightly effective, 3 = moderately effective, 4 = very effective, 5 = extremely effective
Summary and Implications

As we have mentioned elsewhere, the history of scientific inquiry seems firmly based in individual achievement. Our impression that research in the higher education context is a researcher-centric cottage industry is shared by many of the individuals we interviewed for this study.

However, if the Nobel Prize is any gauge of success, collaboration often bears particularly valuable fruit. In the past 25 years, the Nobel Prize for physics has been won by single individuals only three times, and the prize for medicine only four. In the same time frame, the prize in chemistry was won by individuals 9 times (but only twice in the past 10 years), and the prize in economics was won by individuals 13 times (but only three times in the past 10 years). While some instances of multiple winners in science relate to duplicate independent achievements, most seem to speak to the value of collaboration.

Little wonder, then, that higher education institutions and the agencies that fund research at colleges and universities in both the United States and Canada place a priority on collaborative work. From the CIO’s perspective, the fruits of collaboration may be less obvious in terms of the quality of the research being conducted than in the economies of scale that researchers and institutions can gain by sharing technologies like those we’ve discussed in this study with other researchers, and by partnering in various ways with the campus central IT organization.

On average, our respondents were less than enthusiastic in their assessments of the collaborative practices researchers use and the institutional incentives that exist to encourage collaborative behavior. Mean levels of agreement that researchers engage in two such practices and that two such incentives exist were at or below neutral.

Collaboration is difficult to mandate; it represents delicate balances between conflicting wants and needs, and the higher education research context is rich in both. Some of the most appealing models for encouraging cooperation are based not in mechanistic social engineering but in a more naturalistic area, horticulture. In these models, the change agent may sow ideas, in the proper season, in fertile institutional ground, for example, or may cultivate trusting relationships.6

Along these lines, in the first century AD, agriculturalist Lucius Iunius Moderatus Columella wrote, “The eyes and footsteps of the master are things most salutary to the land.” (In more modern times, this has been paraphrased as “The footsteps of the gardener are the best fertilizer.”) This is borne out in several ways by the respondents to our survey (mostly CIO’s, recall, and not without biases). Collaborative practices and incentives to collaborative behavior seem to flourish, at least in relative terms, where the CIO’s “eyes and footsteps” are present—that is, where the CIO makes the technologies available to researchers, funds them, is knowledgeable about them, and has the authority and the resources to support them even when they are not owned by central IT.

The CIO is not the only one who tends the garden of CI collaboration, and the influence of other administrators is felt there as well. A greater level of overall knowledge about most CI technologies attributed by respondents to the CAO, the CRO, and deans in science and engineering, in particular, was associated with more favorable reports about researchers’ collaborative behaviors and institutions’ encouragement of it.

These same factors—central IT as provider and funding source for CI technologies, level of knowledge of the CIO and other officers about CI technologies, and status of CI technology inventories—appear in our findings in relation to respondents’ self-assessment of central IT’s effectiveness at integrating CI resources for support of research. This
suggests that what helps collaboration grow is also helpful in central IT’s efforts to pull CI technologies together to provide seamless support for research.

Our findings for most of the individual CI technologies are similar in many ways, but in several areas those for advanced network infrastructure resources stand out. Compared with the other technologies,

- the pattern of use of advanced networks (at research institutions only) is more pervasive;
- it is more often obtained from and funded by central IT;
- it is marginally more important to all academic areas;
- CIOs report knowing much more about it and about details of its use, and their ability to obtain information about it is much better; and
- institutional inventories of it are complete two to four times more often.

Advanced networking also appears in our questions about accountability, authority, and resources (in terms of bandwidth for research, admittedly a somewhat broader category). It appears as the activity for which CIOs are most often held primarily accountable and as one of the two areas, both bandwidth related, for which CIOs most strongly agree that they have sufficient authority and resources.

As discussed in the introduction to this report, the NSF laid the foundations for advanced network infrastructure resources a decade ago by funding high-speed connections for research institutions. Although funding required evidence that meritorious projects conducted by individuals and teams of researchers would benefit from the increased bandwidth, the award was to the institution. To some extent, we feel, the differences we see in our data for advanced network infrastructure resources reflect this now-mature example of CI funded at the institutional level. More than the other technologies, it has left the realm of the cottage industry and has become a key element of an institutional research enterprise.

Although it would be unwise to carry this notion too far—no single technology behaves in the research environment like all others—we are tempted to see advanced network infrastructure as a weathervane, pointing the direction in which CI will evolve. That direction would be away from ownership and management of CI technologies by individual researchers and toward a common ground of central ownership, management, and support. The flow of funding for CI technologies would be channeled, in part, into budget lines that can be tapped for the common good. And emerging from this husbanding of resources and cultivation of responsibilities, we envision, should be the many fruits of collaborative practice, economies of scale, and a high degree of integration of CI technologies in support of research.

**Endnotes**

Appendix A

Institutional Respondents to the Online Survey

Adler School of Professional Psychology
Air University, USAF
Alliant International University–San Diego
Alvernia College
Antioch University System Administration
Arizona State University
Art Center College of Design
Athabasca University
Azusa Pacific University
Bard College
Bates College
Bemidji State University
Benedictine University
Birmingham-Southern College
Black Hawk College
Black Hills State University
Blue Ridge Community and Technical College
Bluefield College
Board of Regents of the University System of Georgia
Bradley University
Brandeis University
Brevard College
Bridgewater State College
Broome Community College
Butte College
Cabrini College
Caldwell College
California College of the Arts
California Institute of Technology
California State University, Channel Islands
California State University, East Bay
California State University, Sacramento
California State University, San Marcos
California State University, Stanislaus
Calvin College
Camosun College
Campbell University
Canadian University College
Canisius College
Case Western Reserve University
Cecil College
Cedarville University
Central Connecticut State University
Central Methodist University
Central Michigan University
Central Piedmont Community College
Central Wyoming College
Charles Drew University of Medicine & Science
Cincinnati State College
Clemson University
Cleveland State Community College
Colby College
Colgate University
College of Saint Catherine
The College of Saint Scholastica
College of Southern Nevada
Collin County Community College District
Colorado State University
Columbia College Chicago

©2008 EDUCAUSE. Reproduction by permission only.
<table>
<thead>
<tr>
<th>Concordia College</th>
<th>Glendale Community College</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concordia College–Moorhead</td>
<td>Grand Rapids Community College</td>
</tr>
<tr>
<td>Corban College</td>
<td>Grant MacEwan College</td>
</tr>
<tr>
<td>County College of Morris</td>
<td>Green Mountain College</td>
</tr>
<tr>
<td>Dabney S. Lancaster Community College</td>
<td>Hamilton College</td>
</tr>
<tr>
<td>Dalhousie University</td>
<td>Hampton University</td>
</tr>
<tr>
<td>Davenport State College</td>
<td>Harford Community College</td>
</tr>
<tr>
<td>Davis &amp; Elkins College</td>
<td>Harrisburg University of Science and Technology</td>
</tr>
<tr>
<td>Delaware State University</td>
<td></td>
</tr>
<tr>
<td>DePauw University</td>
<td></td>
</tr>
<tr>
<td>Dickinson College</td>
<td>Harvey Mudd College</td>
</tr>
<tr>
<td>Diné College</td>
<td>Houston Community College</td>
</tr>
<tr>
<td>Douglas College</td>
<td>Hudson Valley Community College</td>
</tr>
<tr>
<td>Drexel University</td>
<td>Humber Institute of Technology &amp; Advanced Learning</td>
</tr>
<tr>
<td>East Tennessee State University</td>
<td></td>
</tr>
<tr>
<td>Eastern Oregon University</td>
<td></td>
</tr>
<tr>
<td>Eckerd College</td>
<td></td>
</tr>
<tr>
<td>Elgin Community College</td>
<td></td>
</tr>
<tr>
<td>Elizabeth City State University</td>
<td></td>
</tr>
<tr>
<td>Elmhurst College</td>
<td></td>
</tr>
<tr>
<td>Elmira College</td>
<td></td>
</tr>
<tr>
<td>Embry-Riddle Aeronautical University</td>
<td></td>
</tr>
<tr>
<td>Emory University</td>
<td></td>
</tr>
<tr>
<td>Empire State College SUNY</td>
<td></td>
</tr>
<tr>
<td>The Evergreen State College</td>
<td></td>
</tr>
<tr>
<td>Ferrum College</td>
<td></td>
</tr>
<tr>
<td>Fielding Graduate University</td>
<td></td>
</tr>
<tr>
<td>Florida Community College at Jacksonville</td>
<td></td>
</tr>
<tr>
<td>Florida International University</td>
<td></td>
</tr>
<tr>
<td>Fordham University</td>
<td></td>
</tr>
<tr>
<td>Fort Lewis College</td>
<td></td>
</tr>
<tr>
<td>Fox Chase Cancer Center</td>
<td></td>
</tr>
<tr>
<td>Franklin and Marshall College</td>
<td></td>
</tr>
<tr>
<td>Franklin University</td>
<td></td>
</tr>
<tr>
<td>Franklin W. Olin College of Engineering</td>
<td></td>
</tr>
<tr>
<td>Gallaudet University</td>
<td></td>
</tr>
<tr>
<td>Garden City Community College</td>
<td></td>
</tr>
<tr>
<td>Genesee Community College</td>
<td></td>
</tr>
<tr>
<td>George Fox University</td>
<td></td>
</tr>
<tr>
<td>The George Washington University</td>
<td></td>
</tr>
<tr>
<td>Georgetown University</td>
<td></td>
</tr>
<tr>
<td>Georgia College &amp; State University</td>
<td></td>
</tr>
<tr>
<td>Georgia State University</td>
<td></td>
</tr>
<tr>
<td>Georgian Court University</td>
<td></td>
</tr>
<tr>
<td>Germanna Community College</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Manchester Community College
Manhattan College
Mansfield University of Pennsylvania
Maricopa Community College District
Marietta College
Marquette University
Massachusetts Bay Community College
McKendree University
Medical University of South Carolina
Mercer County Community College
Mercy College of Health Sciences
Mercyhurst College
Meredith College
Miami University
Michigan State University
Middle Tennessee State University
Middlebury College
Middlesex County College
Midland College
Millikin University
Millsaps College
Minot State University
Mississippi Valley State University
Missouri Southern State University
Missouri State University–West Plains
MIT
Monmouth College
Monroe Community College
Montana State University
Montana State University–Great Falls, College of Technology
Mount Holyoke College
Mount Union College
Mountain Empire Community College
Nashville State Community College
Nebraska Wesleyan University
Nevada System of Higher Education
New Jersey Institute of Technology
Newbury College
Nipissing University
North Carolina School of the Arts
North Central College
North Dakota State University
Northern Illinois University
Northwestern Health Sciences University
Northwestern University
Nova Scotia Community College
Oakland University
Oberlin College
Ocean County College
Ohio Northern University
Oklahoma Baptist University
Oklahoma State University
Onondaga Community College
Oregon State University
Otterbein College
Our Lady of the Lake University
Paradise Valley Community College
Pennsylvania College of Technology
The Pennsylvania State University
Phoenix College
Pomona College
Presbyterian College
Prince George’s Community College
Princeton University
Providence College
Purdue University
Ramapo College of New Jersey
Raritan Valley Community College
Reading Area Community College
Rhodes College
Robert Morris University
Rochester Institute of Technology
Roosevelt University
Rosalind Franklin University of Medicine and Science
Rose State College
Rutgers, The State University of New Jersey
Rutgers, The State University of New Jersey/Newark
Saint Joseph’s College, New York
Saint Louis Community College
Saint Louis University
Saint Mary’s College
Saint Mary’s College of California
Saint Mary’s University of Minnesota
Salem State College
Samford University
San Juan College
Santa Barbara City College
Savannah College of Art and Design
School of the Art Institute of Chicago
Schreiner University
Seattle Pacific University
Seattle University
Seton Hall University
Shepherd University
Simon Fraser University
South Dakota State University
South Texas College of Law
Southern Illinois University Edwardsville
Southern Methodist University
Southern Oregon University
Southern State Community College
Southern Wesleyan University
St. Cloud State University
St. John Fisher College
St. Philip’s College
Sullivan University
SUNY College at Old Westbury
SUNY College at Oswego
SUNY College of Technology at Delhi
Sweet Briar College
Tennessee State University
Texas A&M University at Galveston
Texas State University–San Marcos
Texas Wesleyan University
Thomas Nelson Community College
Towson University
Trinity College
Trinity University
Truckee Meadows Community College
Tufts University
UCLA
Union County College
United States Air Force Academy
Université de Montréal
University at Albany, SUNY
University at Buffalo
University of Alabama
University of Alabama at Birmingham
University of Alaska
University of Alaska Fairbanks/Kuskokwim
The University of Arizona
The University of the Arts
University of Baltimore
The University of British Columbia
University of Calgary
University of California Office of the President
University of California, Berkeley
University of California, Davis
University of California, Merced
University of California, Riverside
University of California, San Diego
University of Central Oklahoma
University of Colorado at Boulder
University of Connecticut
University of Delaware
University of Denver
University of Florida
University of Hawai‘i
University of Indianapolis
University of La Verne
University of Louisville
University of Maine System
University of Manitoba
University of Maryland
University of Maryland, Baltimore
University of Maryland, Baltimore County
University of Massachusetts Boston
University of Medicine & Dentistry of New Jersey
The University of Memphis
University of Michigan–Ann Arbor
University of Minnesota
University of Minnesota Duluth
University of Mississippi
The University of Montana
University of Nebraska
University of Nebraska–Lincoln
University of Nebraska at Kearney
University of Nebraska at Omaha
University of Nevada, Las Vegas
University of New England
University of New Mexico
University of North Carolina at Greensboro
University of North Carolina at Pembroke
University of North Dakota
University of North Texas
University of Northwestern Ohio
University of Notre Dame
University of Ottawa
University of Pennsylvania
University of Rochester
University of South Carolina
University of South Florida
University of Southern California
University of Southern Mississippi
University of Tennessee at Chattanooga
University of Texas at Austin
University of Texas of the Permian Basin
University of the Incarnate Word
University of the Pacific
University of the Sciences in Philadelphia
The University of South Dakota
The University of Tennessee
University of Vermont
University of Victoria
University of West Florida
University of Windsor
University of Wisconsin Extension
University of Wisconsin–Madison
University of Wisconsin–Milwaukee
University of Wisconsin–Platteville
University of Wisconsin–River Falls
University of Wisconsin–Stout
University System of Maryland
Valparaiso University
Vanderbilt University
Virginia Highlands Community College
Virginia Tech
Wagner College
Wake Forest University
Walters State Community College
Washington College
Wayne State University
Webster University
Wellesley College
West Liberty State College
West Virginia School of Osteopathic Medicine
Westchester Community College
Western Connecticut State University
Western New Mexico University
Whitehead Institute for Biomedical Research
Whitman College
Willamette University
Yale University
Zane State College
Appendix B

Interviewees in Qualitative Research

Athabasca University
   Brian Stewart, CIO

Case Western Reserve University
   Lev Gonick, Vice President for Information Technology Services and CIO

Colorado State University
   Patrick Burns, Vice President for Information Technology

Indiana University
   Craig Stewart, Director, Research and Academic Computing

Miami University
   Carolyn Gard, Senior Director for Academic Technology Services
   David Woods, Assistant Director for Research Computing

Paradise Valley Community College
   Carol Myers, Director, College Technology

The Pennsylvania State University
   Kevin Morooney, Vice Provost for Information Technology and CIO

Seattle University
   Bo Vieweg, Director of the Office of Information Technology

University of Michigan
   Kathleen Bauer, Assistant Vice Provost for Academic Information

University of Southern California
   Ilee Rhimes, CIO and Vice Provost for Information Technology Services

University of Victoria
   Mark Roman, CIO

©2008 EDUCAUSE. Reproduction by permission only.
Appendix C  

Bibliography


## Appendix D

### Statistical Details (Selected Tables)

Table 6-2. Agreement That Incentives Exist, by Agreement That CIO Has Sufficient Authority and Resources to Meet Responsibilities (Full Statistics)

<table>
<thead>
<tr>
<th>Level of Agreement That CIO Has Sufficient Authority and Resources to Meet Responsibilities</th>
<th>Mean Agreement That Institutional Incentives Exist for Researchers to Share Resources*</th>
<th>Mean Agreement That Institutional Incentives Exist for Researchers to Partner with Central IT*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Authority</td>
<td>Resources</td>
</tr>
<tr>
<td></td>
<td>N</td>
<td>Mean*</td>
</tr>
<tr>
<td><strong>Service Activities</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Support services for research systems</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Disagree</td>
<td>26</td>
<td>2.27</td>
</tr>
<tr>
<td>Neutral</td>
<td>43</td>
<td>2.53</td>
</tr>
<tr>
<td>Agree</td>
<td>206</td>
<td>2.79</td>
</tr>
<tr>
<td>Total</td>
<td>275</td>
<td>2.70</td>
</tr>
<tr>
<td>Research system security</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Disagree</td>
<td>41</td>
<td>2.27</td>
</tr>
<tr>
<td>Neutral</td>
<td>43</td>
<td>2.28</td>
</tr>
<tr>
<td>Agree</td>
<td>192</td>
<td>2.91</td>
</tr>
<tr>
<td>Total</td>
<td>276</td>
<td>2.71</td>
</tr>
<tr>
<td>Ongoing maintenance of non-central research resources</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Disagree</td>
<td>89</td>
<td>2.39</td>
</tr>
<tr>
<td>Neutral</td>
<td>44</td>
<td>2.91</td>
</tr>
<tr>
<td>Agree</td>
<td>140</td>
<td>2.89</td>
</tr>
<tr>
<td>Total</td>
<td>273</td>
<td>2.73</td>
</tr>
<tr>
<td>Enforcing regulatory compliance</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Disagree</td>
<td>90</td>
<td>2.51</td>
</tr>
<tr>
<td>Neutral</td>
<td>60</td>
<td>2.53</td>
</tr>
<tr>
<td>Agree</td>
<td>117</td>
<td>2.96</td>
</tr>
<tr>
<td>Total</td>
<td>267</td>
<td>2.71</td>
</tr>
</tbody>
</table>

Cont’d
### Infrastructure Activities

#### Bandwidth for research

<table>
<thead>
<tr>
<th>Level of Agreement</th>
<th>Mean Agreement That Institutional Incentives Exist for Researchers to Share Resources*</th>
<th>Mean Agreement That Institutional Incentives Exist for Researchers to Partner with Central IT*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Authority</td>
<td>Resources</td>
</tr>
<tr>
<td></td>
<td>N</td>
<td>Mean*</td>
</tr>
<tr>
<td>Disagree</td>
<td>9</td>
<td>2.11</td>
</tr>
<tr>
<td>Neutral</td>
<td>22</td>
<td>2.32</td>
</tr>
<tr>
<td>Agree</td>
<td>266</td>
<td>3.02</td>
</tr>
<tr>
<td>Total</td>
<td>297</td>
<td>2.94</td>
</tr>
</tbody>
</table>

#### Bandwidth for teaching and learning

<table>
<thead>
<tr>
<th>Level of Agreement</th>
<th>Mean Agreement That Institutional Incentives Exist for Researchers to Share Resources*</th>
<th>Mean Agreement That Institutional Incentives Exist for Researchers to Partner with Central IT*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Authority</td>
<td>Resources</td>
</tr>
<tr>
<td></td>
<td>N</td>
<td>Mean*</td>
</tr>
<tr>
<td>Disagree</td>
<td>43</td>
<td>2.47</td>
</tr>
<tr>
<td>Neutral</td>
<td>31</td>
<td>2.52</td>
</tr>
<tr>
<td>Agree</td>
<td>241</td>
<td>3.05</td>
</tr>
<tr>
<td>Total</td>
<td>315</td>
<td>2.92</td>
</tr>
</tbody>
</table>

#### Storage for research data

<table>
<thead>
<tr>
<th>Level of Agreement</th>
<th>Mean Agreement That Institutional Incentives Exist for Researchers to Share Resources*</th>
<th>Mean Agreement That Institutional Incentives Exist for Researchers to Partner with Central IT*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Authority</td>
<td>Resources</td>
</tr>
<tr>
<td></td>
<td>N</td>
<td>Mean*</td>
</tr>
<tr>
<td>Disagree</td>
<td>39</td>
<td>2.31</td>
</tr>
<tr>
<td>Neutral</td>
<td>40</td>
<td>2.45</td>
</tr>
<tr>
<td>Agree</td>
<td>199</td>
<td>2.85</td>
</tr>
<tr>
<td>Total</td>
<td>278</td>
<td>2.72</td>
</tr>
</tbody>
</table>

#### Space and environmental support

<table>
<thead>
<tr>
<th>Level of Agreement</th>
<th>Mean Agreement That Institutional Incentives Exist for Researchers to Share Resources*</th>
<th>Mean Agreement That Institutional Incentives Exist for Researchers to Partner with Central IT*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Authority</td>
<td>Resources</td>
</tr>
<tr>
<td></td>
<td>N</td>
<td>Mean*</td>
</tr>
<tr>
<td>Disagree</td>
<td>88</td>
<td>2.33</td>
</tr>
<tr>
<td>Neutral</td>
<td>58</td>
<td>2.90</td>
</tr>
<tr>
<td>Agree</td>
<td>107</td>
<td>2.84</td>
</tr>
<tr>
<td>Total</td>
<td>253</td>
<td>2.68</td>
</tr>
</tbody>
</table>

*Scale: 1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, 5 = strongly agree*
Table 6-6. Effectiveness at Integrating Cyberinfrastructure Technologies, by Overall Knowledge of the Technologies

<table>
<thead>
<tr>
<th>Knowledge</th>
<th>Chief Information Officer</th>
<th>Chief Academic Officer</th>
<th>Chief Research Officer</th>
<th>Science and Engineering Deans</th>
<th>Other Deans</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>Mean*</td>
<td>Std. Deviation</td>
<td>N</td>
<td>Mean*</td>
</tr>
<tr>
<td>High-performance computing</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Poor/fair</td>
<td>46</td>
<td>1.98</td>
<td>0.715</td>
<td>83</td>
<td>2.39</td>
</tr>
<tr>
<td>Good</td>
<td>47</td>
<td>2.66</td>
<td>0.788</td>
<td>39</td>
<td>2.90</td>
</tr>
<tr>
<td>Very good/excellent</td>
<td>81</td>
<td>3.15</td>
<td>0.808</td>
<td>44</td>
<td>3.18</td>
</tr>
<tr>
<td>Total</td>
<td>174</td>
<td>2.71</td>
<td>0.913</td>
<td>166</td>
<td>2.72</td>
</tr>
<tr>
<td>CI applications and tools</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Poor/fair</td>
<td>94</td>
<td>2.09</td>
<td>0.825</td>
<td>136</td>
<td>2.43</td>
</tr>
<tr>
<td>Good</td>
<td>77</td>
<td>2.84</td>
<td>0.779</td>
<td>54</td>
<td>2.87</td>
</tr>
<tr>
<td>Very good/excellent</td>
<td>70</td>
<td>3.13</td>
<td>0.916</td>
<td>38</td>
<td>3.00</td>
</tr>
<tr>
<td>Total</td>
<td>241</td>
<td>2.63</td>
<td>0.949</td>
<td>228</td>
<td>2.63</td>
</tr>
<tr>
<td>Data storage and management</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Poor/fair</td>
<td>72</td>
<td>2.24</td>
<td>0.796</td>
<td>136</td>
<td>2.42</td>
</tr>
<tr>
<td>Good</td>
<td>72</td>
<td>2.56</td>
<td>0.870</td>
<td>59</td>
<td>2.90</td>
</tr>
<tr>
<td>Very good/excellent</td>
<td>89</td>
<td>3.08</td>
<td>0.907</td>
<td>26</td>
<td>3.23</td>
</tr>
<tr>
<td>Total</td>
<td>233</td>
<td>2.66</td>
<td>0.930</td>
<td>221</td>
<td>2.64</td>
</tr>
<tr>
<td>Advanced network infrastructure</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Poor/fair</td>
<td>87</td>
<td>2.59</td>
<td>0.870</td>
<td>49</td>
<td>2.57</td>
</tr>
<tr>
<td>Good</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Very good/excellent</td>
<td>36</td>
<td>3.22</td>
<td>0.832</td>
<td>11</td>
<td>3.36</td>
</tr>
<tr>
<td>Total</td>
<td>172</td>
<td>2.72</td>
<td>0.915</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Collaboration within virtual communities</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Poor/fair</td>
<td>69</td>
<td>2.35</td>
<td>0.801</td>
<td>117</td>
<td>2.56</td>
</tr>
<tr>
<td>Good</td>
<td>79</td>
<td>2.84</td>
<td>0.741</td>
<td>56</td>
<td>3.07</td>
</tr>
<tr>
<td>Very good/excellent</td>
<td>69</td>
<td>3.12</td>
<td>1.065</td>
<td>34</td>
<td>2.94</td>
</tr>
<tr>
<td>Total</td>
<td>217</td>
<td>2.77</td>
<td>0.924</td>
<td>207</td>
<td>2.76</td>
</tr>
</tbody>
</table>

*Scale: 1 = not effective, 2 = slightly effective, 3 = moderately effective, 4 = very effective, 5 = extremely effective