7. IF WE BUILD IT, WILL THEY COME? THE CULTURAL CHALLENGES OF CYBERINFRASTRUCTURE DEVELOPMENT

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Abstract: In this chapter, we show how Hofstede's cultural constructs help explain the dysfunction we observed in the early history of the George E. Brown, Jr., Network for Earthquake Engineering Simulation (NEES), a large-scale deployment of cyberinfrastructure intended to link 16 experimental facilities around the United States. The NEES project involved participants from three distinct professional cultures: civil engineering, computer science, and program managers at the U.S. National Science Foundation. Using Hofestede's categories, we demonstrate how mis-communication arose from orthogonal orientations on Hofstede's dimensions. In particular, we found that variation in attitudes toward risk led to conflict, with the more risk-averse civil engineers and program managers frequently aligned against the more risk-tolerant computer scientists. In the discussion, we consider successful techniques for accommodating differences in professional cultures and offer a set of lessons learned based on experience with the NEES project.

Cyberinfrastructure and the "Third Way"

The convergence of information technology and research, in what some have called "cyberscience" (Nentwich, 2003), represents a potentially revolutionary change in the conduct and organization of scientific inquiry. Specifically, recent expert reports, such as by the National Science Foundation's blue-ribbon panel on cyberinfrastructure (Atkins *et al*. 2003), suggest that advances in computing and networking may transform intellectual work in ways similar to the transformation of physical work that occurred during the Industrial Revolution. That is, just as innovations in physical infrastructure unleashed new forms of production and distribution, innovations in cyberinfrastructure are expected to foster new discoveries based on the ability to capture and analyze more data at increasingly higher resolution, to generate simulations with greater detail and accuracy, and to interact and collaborate with colleagues independent of time and distance.

In particular, noting the theme of this collection around "converging technologies," it is important to emphasize that to a great extent, the

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transformative power of cyberinfrastructure lies in its potential to bring multiple scientific or engineering disciplines together. Sometimes these unions become the basis for new, converged disciplines such as the emergence of computational biology and chemistry around the combination of these traditional fields with computer science (e.g., simulations of molecular dynamics or visualizations of chemical structures). However, disciplinary convergence is not an automatic result of cyberinfrastructure. As this chapter illustrates, there are still critical challenges to convergence in the form of underlying socio-technical factors, such as the differences in work practices and world views that complicate the relationship between users and developers of cyberinfrastructure.

Observing an earlier period, when dramatic changes in the organization of scientific work produced new convergence, Sir Humphrey Davy noted: “Nothing tends so much to the advancement of knowledge as the application of a new instrument.” (Hager, 1995: 86). Of course, Davy was referring to his own voltaic pile and similar inventions, which were both the source of key discoveries (e.g., identification of new elements) and the cause for the emergence of new organizational forms (e.g., the professional laboratory, such as the Royal Institution, which Davy founded). Today, cyber-infrastructure is a new kind of instrument, in the sense that through high-performance computing and networking, scientists are able to generate data and test hypotheses beyond the limits of traditional theory or experiment-based approaches. Specifically, in the words of the Atkins report, computational simulations provide a “third way” to do research at unprecedented levels of temporal and spatial fidelity. For example, visualizations of weather models run on supercomputers can provide atmospheric scientists with virtual perspectives on large-scale systems, such as tornadoes emerging from storm cells.

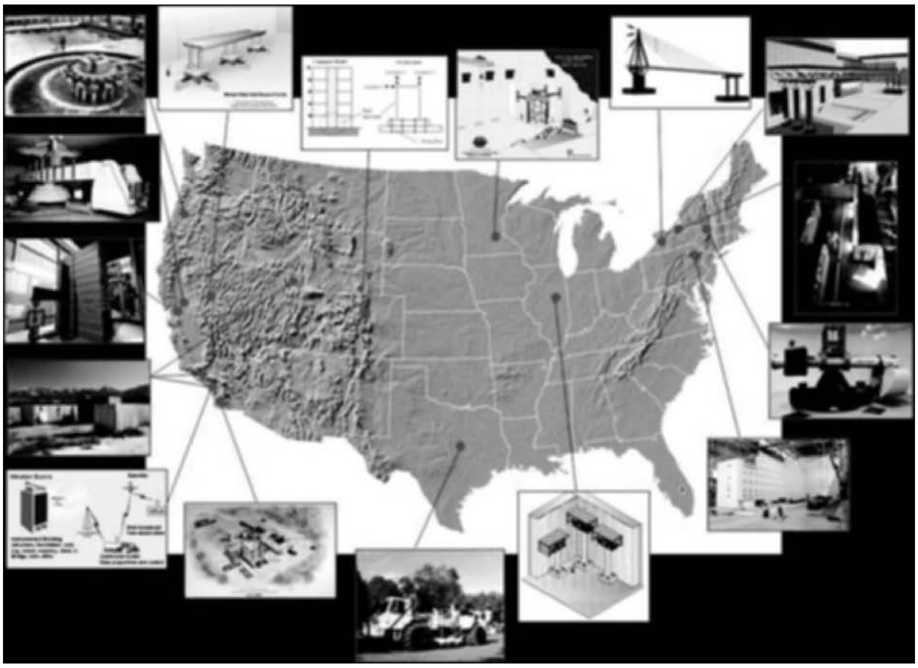
Barriers to Cyberinfrastructure

The capacity to use cyberinfrastructure to instrument phenomena *in silico* is expected to accelerate the pace of scientific discovery and of innovation based on these discoveries. Yet a number of barriers exist that may limit this potential. A key obstacle is the availability of funds. For example, federal sponsors are expected to play a central role in making the lead investments in cyberinfrastructure that will signal the need for subsequent larger investments from other sectors, such as industry and academia. One model for this evolution is NSFnet, in which a relatively modest level of funding from the National Science Foundation (NSF) was leveraged by significant contributions from universities and corporations, with the result being the birth of broadly interoperable networks around the TCP/IP standard adopted within NSFnet. The Atkins report calls for the NSF to make a $1 billion lead investment in cyberinfrastructure. Given current budget levels, such as the essentially flat appropriation for NSF in the FY 2005 federal budget, it seems unlikely that anything approaching the scope of the Atkins report recommendations will be carried out soon. However, NSF did recently create the new division of shared cyberinfrastructure (SCI) within the computing and information science and engineering (CISE) directorate, which has on the order of $120 million to fund cyber-infrastructure awards. In addition, several directorates have identified existing funding, sometimes totaling several hundred million dollars, in cyberinfrastructure-related programs, such as the George E. Brown, Jr., Network for Earthquake Engineering Simulation (NEES), an $89 million collaboratory funded by the engineering directorate. A collaboratory is a form of cyberinfrastructure that brings together resources (e.g., instruments), people, and data via computer-supported systems (Finholt, 2003).

NEES began in 2001, and during the development phase (2001-2004) it consisted of three elements. First, the majority of resources went to construct new earthquake engineering (EE) facilities at 15 institutions. Figure 1 shows the location and capabilities of these new labs. Second, $10 million went to a consortium led by the National Center for Supercomputing Applications at the University of Illinois to develop NEESgrid, the cyberinfrastructure to link the new labs. Finally, $3 million went to the Consortium for University Research in Earthquake Engineering to build and launch the NEES Consortium, Inc., or the nonprofit entity that NSF would fund over the period 2004-2014 to maintain and operate the NEES systems. As of October 1, 2004, operational control over NEES passed to the NEES Consortium, and the grand opening ceremony for NEES was held on November 15, 2004.

Our role in the NEES program was to investigate and enumerate the user requirements for NEESgrid. Thus, we were an interface between the earthquake engineers (the target users of the system), the NSF program managers (the customer), and the computer scientists (the system developers). In the process of gathering user requirements during the period 2000–2003, we attended 10 national meetings and workshops of engineers and system developers, as well as six site reviews of the project by an independent panel, and also participated in weekly videoconferences on the progress of the project with engineers, developers, and program managers. We have also visited the 15 NEES equipment sites and conducted over 75 interviews with earthquake engineers, as well as conducted four national surveys of communication and collaboration practices within the EE community. Through these activities, we had many opportunities to observe key participants in the NEES program and to catalog various breakdowns of communication and trust.

Figure 1. Type and Geographic Distribution of the NEES Facilities



All of our data-gathering activities were approved by the behavioral science institutional review board (i.e., human subjects) at the University of Michigan. All data collection, observation, and interviews were conducted with the informed consent of the NEES participants. The conclusions drawn from the data are our own and do not reflect official positions of the leadership of the various NEES projects or of the National Science Foundation. The object of our analysis is to highlight general problems that can arise in interdisciplinary collaborations around the development of cyberinfrastructure, and not to cast blame on specific individuals or groups. Finally, consistent with ethical social science research practice, we have removed any information that might identify specific individuals or groups.

Because NEES is a pioneering effort to move an entire community of researchers to cyberinfrastructure, there are a number of key lessons to draw from the experience and the data we collected. Notably, the development, deployment, and adoption of NEES illustrate the role cultural orientation can play in a cyberinfrastructure project. That is, the degree to which respective professional cultures align or are in conflict – in this case, earthquake engineers, cyberinfrastructure developers, and NSF program managers – can influence the success of cyberinfrastructure efforts.

Cultural Orientation

In his famous analysis, Hofstede (1980, 1991), proposed four fundamental dimensions that reliably differentiate national cultures: uncertainty avoidance, power distance, gender, and individualism. With some modest adjustment, these same dimensions can be used to describe differences in what might be called "professional cultures." Professional cultures are to people who work and were socialized in different fields of work as national cultures are to people who live and were socialized in different countries. In this case, we argue that the NEES project brought together participants from three areas of work, each with its own unique professional culture: earthquake engineers, who were the target users of the NEES cyberinfrastructure; NSF program managers, who were the principal "customers" for the delivered systems (both facilities and cyberinfrastructure); and computer scientists, who were the cyber-infrastructure developers. Despite broad endorsement of NEES by all participants, early interactions between the main groups were problematic and quickly led to mistrust.

Difficulties in NEES had the character of a "first contact" gone awry. That is, in accounts of European exploration in the New World (e.g., Ruby, 2001), a recurring theme is the inability of the Europeans to step outside their own cultural framework – with one result being a history of disastrous relations with native populations. Similarly, in the NEES project, representatives of the three key groups entered their initial collaborations assuming a common worldview. Subsequent discovery of divergent perspectives was initially a cause of communication failures and later the basis for open hostility. Hofstede's dimensions, when applied to the professional cultures represented in NEES, provide a helpful starting place for understanding why the start of the NEES project was so hard, and also why changes to the project over time eventually corrected some of the early problems and increased the likelihood of success.

Whereas Hofstede provides four dimensions on which cultures can be distinguished, we found two of these to be particularly relevant in characterizing the early NEES participants – uncertainty avoidance and power distance. Uncertainty Avoidance is the extent to which individuals take steps to control risk and the unknown. Power Distance is the extent to which individuals prefer formal and hierarchical relationships compared to more informal and egalitarian relationships. The sub-sections below characterize each type of NEES participant according to these two dimensions, with particular attention to how groups differed and how these differences led to negative consequences for project development.

Earthquake Engineers

Earthquake engineering (EE) is concerned with the seismic performance of the built environment (Sims, 1999). Their research work typically consists of experiments conducted on large, physical models of buildings, bridges, and soil-retaining structures (e.g., retaining walls, building foundations, etc.) that are outfitted with hundreds of sensors that record details of strain and motion in simulated earthquakes generated by means of large shaking platforms or hydraulic actuators. EE as a field reflects some degree of convergence, to the extent that researchers must understand both characteristics of ground motion related to seismic activity and the effects of this ground motion on buildings and other physical infrastructure. In addition, researchers typically combine analytic activity with experimental activity, such as computational simulations conducted to determine the range of behavior for a specimen that will be tested in a physical simulation. For the most part, however, EE researchers tend to be trained as civil engineers (and most are certified as professional engineers) and tend to apply computational simulations in support of physical simulations (rather than as substitutes, which is to say that there is not yet any analog in EE research for the computationally based subdisciplines that have emerged in other fields, such as computational chemistry or biology).

Uncertainty Avoidance. Earthquake engineers generally seek to avoid or control uncertainty. Experimental specimens in EE are typically built of steel or reinforced concrete, as are the "real-world" structures that these specimens represent. Such materials are difficult to modify once constructed, and there is therefore a tremendous amount of planning and analysis that goes into the design of an experimental specimen. Uncertainty, and the accompanying potential for changes, errors, and unpredictable structural behavior, is thus seen as a significant potential liability in this community and is actively avoided. This risk aversion in experimental work is indicative of a generally conservative orientation among earthquake engineers that makes them suspicious of tools and methods that are new and untested.

Power Distance. EE is generally distinguished by high power distance. Among earthquake engineers, there is a tendency to defer to authority figures both within local laboratories and in the field more generally. Power distance is reflected at the field level in the distribution of experimental apparatus. A small number of large-scale facilities define a clear set of elite institutions that are better ranked (e.g., by the National Research Council), publish more, obtain more funding, and attract better graduate students. At the local level, power distance is reflected in the division of labor in the laboratories, with some tasks clearly intended for undergraduate lab assistants versus graduate students versus technicians and faculty. In addition, graduate students work primarily on projects initiated and led by their advisors, rather than on projects they devise independently.

Cyberinfrastructure Developers

The NEES cyberinfrastructure development effort was based on a number of open source software codes, notably those needed to enable "grid-based" systems (Foster and Kesselman, 1999). As a result, although not strictly an open source project, NEES developers did resemble open source programmers described elsewhere, such as in DiBona, Ockman, and Stone (1999). In other words, they exhibited an egalitarian orientation with a preference for informal organization.

Uncertainty Avoidance. The cyberinfrastructure developers were not risk averse and can therefore be characterized as low on the uncertainty avoidance dimension. Specifically, the developers worked using spiral software development models (Boehm, 1995) that advocated rapid iteration and prototyping. Such a strategy actively encourages risk-taking and sometimes ill-specified development activities because it is assumed that problems can be eliminated in the next iteration, which is never far away and does not have a high cost. Thus, there was little perceived need to eliminate uncertainty early in the project, as errors were expected and would be addressed in the subsequent development cycles. This is captured well in one of the NEES software developers' frequent use of the motto "don't worry, be crappy" to describe the incremental approach to risk inherent in the spiral model.

Power Distance. Power distance among cyberinfrastructure developers was low. Individual programmers often had broad latitude to determine how to proceed with development, provided they remained consistent with overarching design directions. Further, in interactions among the developers, people participated largely independent of their status or seniority, with the exception of sometimes deferring to others with deeper technical expertise.

NSF Program Managers

Program officers in the NSF are responsible for overseeing the distribution and management of resources in ways that promote the goals of the Foundation. With much grant-based research, this tends to be accomplished via a reasonably "hands-off" approach. NEES, however, differed from typical grants in critical respects. First, NEES was a high-profile project in terms of funding level and was awarded as a "cooperative agreement," which imposed a higher than typical oversight burden on NSF. Second, NEES was the first major research equipment and facility construction project in the engineering directorate. Finally, NEES was the first attempt by NSF to build a network of facilities linked by cyberinfrastructure.

Uncertainty Avoidance. Uncertainty avoidance was high among the NSF managers. First, many came from the EE and civil engineering cultures and shared the pervasive risk aversion of colleagues from these communities. Second, because of the cost and visibility of NEES, the stakes were quite high for individual managers, particularly in terms of career advancement.

Power Distance. Power distance among the NSF managers was high. That is, particularly because of the cooperative agreement governing NEES, NSF managers intervened more actively in the conduct of the project. Because this differed from the usual experience with grant-based research, NEES investigators chafed under the closer scrutiny of the NSF staff. For example, rather than the collegial relationship characteristic of grant-based activity, the cooperative agreement created a hierarchical relationship. In some cases, particularly around NSF requests for documentation and justification, NEES investigators felt they were treated as subordinates – or mere contractors – rather than as leading researchers in computer science or earthquake engineering.

Consequences of Cultural Differences

One episode that illustrated the gulf between earthquake engineers and cyberinfrastructure developers emerged around the release of the initial user requirements report by the cyberinfrastructure development team. The report, grounded in the principles of user-centered design and based on substantial interview and survey data, outlined at a high level the comprehensive user requirements for the NEESgrid collaboratory. The earthquake engineers were almost universally disappointed with the user requirements report. Specifically, the earthquake engineers and the cyberinfrastructure developers had divergent notions of what constituted "requirements" that at least partially reflected differences in their professional cultures.

The engineering notion of requirements was specific with detailed characterization of functionality, implementation, and relationship to other requirements. This approach to user requirements was consistent with both the engineers' cultural bias against uncertainty and their preference for formal and hierarchical relationships. That is, a precise and exhaustive requirements document early in a project allows for elimination of potential problems and for clear division of labor. The cyberinfrastructure developers, in contrast, had a less rigid view of requirements. The spiral development model they adopted suggested that it would be difficult or impossible to resolve all uncertainties early on, so the best approach was to specify requirements at a high level, implement to satisfy these initial requirements, and then iterate to improve both requirements specification and implementation. This approach struck the earthquake engineers as sloppy and unnecessarily risky. Differences about the meaning of requirements served to create a rift between the developers and earthquake engineers, because neither side believed the other knew what "requirements" were or how to correctly document them. This fostered mistrust and vastly increased the need for communication and bridge-building between the communities.

Another episode that underlined the difficulty of negotiating cultural differences among the NEES players was the "emergency all-hands meeting" convened by NSF program managers just a few months after the project began. The primary issue at this meeting was a misunderstanding over the nature of project deliverables. The cyberinfrastructure developers argued that they had received funding to produce a set of grid-based telecontrol protocols and Application Program Interfaces (APIs) for integrating equipment at different laboratories and for providing telepresence functionality. The earthquake engineers, and to some extent the NSF program managers, thought they were getting a turnkey system, and were shocked to learn that they would have to hire programmers and learn to use APIs in order to make the NEES system functional. After one long discussion in which the computer scientists fended off a growing list of deliverables as "out of scope," a disgusted earthquake engineer observed of the cyberinfrastructure developers that "we wouldn't buy a used car from you guys" – reflecting the sense that the engineers had been sold a "lemon."

Again, this conflict can be explained along cultural lines. The desire of the earthquake engineers to avoid costly uncertainty explains the extent to which they bristled at the surprising discovery of what they perceived as the deficient scope of the cyberinfrastructure development activity. Similarly, the response of the cyberinfrastructure developers reflected their cultural orientation toward maintaining flexibility to address interesting issues as they arose, rather than being firmly committed to carry out tasks that might prove to be dead ends or time sinks. One measure of the cultural disconnect between the two sides was that at this meeting, and other subsequent sessions, the computer scientists brushed off the engineers' concerns (often using humor), not realizing the growing irritation on the part of the engineers. Specifically, at a moment when both sides needed to develop common ground, their cultural dispositions caused them to dig in and oppose each other.

Discussion and Lessons Learned

This chapter highlights professional culture conflict as a previously undocumented source of risk in cyberinfrastructure initiatives. That is, because cyberinfrastructure involves the blending of effort between computer scientists and one or more communities of domain scientists or engineers, there is a greater than normal chance for misunderstanding and mistrust arising from cultural differences. Further, because of the cost and visibility of cyberinfrastructure projects, federal program managers typically represent a third cultural perspective, one that is often at odds with the other perspectives. As the preceding sections have shown, failure to understand and accommodate cultural differences can result in awkward first contacts, and subsequent difficulty in building understanding and confidence among participants from separate professional cultures. In this section we describe some of the steps taken to overcome cultural barriers in the NEES project and then use these experiences to describe a general set of lessons learned that can help other cyberinfrastructure efforts avoid repeating the NEES mistakes.

Strategies Adopted to Overcome Cultural Differences

After a problematic start to the NEES development and deployment, key players from each of the participating groups explored and adopted strategies to help overcome cultural differences. First, there was general agreement that all parties needed more opportunities to communicate. One important step, therefore, was taken halfway through the first year of NEES development, when cyberinfrastructure developers, earthquake engineers, and NSF program managers agreed to convene a weekly, multi-point videoconference (Hofer *et al*., 2004). The format of these conferences allowed for the presentation and discussion of a specific concern each week, along with some time for general discussion. Responsibility for these meetings was traded off between the earthquake engineers and the cyberinfrastructure developers. These weekly conferences were widely viewed as being tremendously helpful in getting the NEES project participants to understand each other better.

A second strategy for overcoming cultural differences involved explicit efforts to increase the diversity of involvement in cyberinfrastructure development. For the first 2 years, the project directors for the NEES collaboratory effort were closely aligned with the cyberinfrastructure developer culture. Because of the strained relations that emerged between the earthquake engineers and the cyberinfrastructure developers, the lack of a strong earthquake engineering voice in the development process became a focus for criticism from both earthquake engineers and the NSF program managers. Therefore, shortly before the start of the final year of the project there was a leadership change. A prominent earthquake engineer who had a strong relationship with all of the communities involved was selected to lead the NEES collaboratory effort, and this had a positive impact on relations between the participating groups. In particular, the new project director was able to serve as a translator, effectively smoothing over many of the misunderstandings and the mistrust that had emerged early in the project.

Lessons Learned from the NEES Experience

We believe the experience with NEES, during the period 2001–2004, offers a set of general lessons that can be applied to other cyberinfrastructure projects. The following list represents our recommendations for subsequent cyberinfrastructure efforts.

- Lesson 1: A domain scientist or engineer must be a leader or co-leader of cyberinfrastructure development and deployment. This does not mean that technology experts should be pushed aside but, rather, that the best insurance against an overly ambitious technological agenda is the presence of a domain scientist or engineer to consistently enforce attention to documented user requirements. In the Atkins report (2003), this tension is identified as the strain between the desire of cyberinfrastructure developers to pursue novel computer science research against the need by domain scientists and engineers to have reliable production environments.
- Lesson 2: Where possible, project participants should err on the side of clarifying and mitigating sources of uncertainty. This does not mean that cyberinfrastructure development should avoid risk or that all risks must be enumerated in advance. However, all parties should develop a common understanding of how to approach and manage risk. For example, as much as academic computer scientists may chafe under constraints imposed by formal project management, articulating precise deliverables and timelines is a critical way to create shared expectations across cultural divisions. Of course, having identified critical deliverables, it is essential that these be accomplished on schedule – particularly as parallel streams of work (e.g., collaboratory development and facility construction) often involve complicated dependencies.
- Lesson 3: Communication about project status must be regular, frequent, across multiple levels, and via multiple media. A quarterly or semiannual "all hands" meeting is not sufficient for handling the complexity that arises in a cyberinfrastructure project. Similarly, exclusive communication through electronic means (e.g., e-mail) increases the likelihood of misinterpretation – particularly early in a project. Instead, projects should encourage a number of ways to communicate, both formal and informal. Travel funds should be spent to encourage frequent face-to-face contact, especially during start-up phases. The ability to associate a face and a friendly relationship with a name that otherwise appears only in one's e-mail in-box often protects against harsh attributions that can arise between participants from different professional cultures.

- Lesson 4: There should be frequent and public affirmation of project accomplishments at venues and conferences that are important to all participating groups. For instance, in the NEES project critical technology demonstrations were conducted at meetings attended primarily by computer scientists, such as the annual supercomputing conferences, but also at meetings significant to earthquake engineers, such as the World Conferences on Earthquake Engineering, held every 2 years. These public demonstrations create a development discipline that focuses attention on integration and functionality in a way that all participants can understand and evaluate.

Implications for NBIC Convergence

We believe that the situations, experiences, and lessons from NEES are instructive when considering the convergence between nanotechnology, biology, information technology, and cognitive science (NBIC). That is, the form of cultural conflict between these fields may be different than what we observed with NEES, but we are confident that the unique disciplinary identities represented when bringing together the NBIC fields will require the same kind of explicit measures that we saw adopted within the NEES project. One difference that may distinguish NBIC convergence from the NEES case is the greater exposure and use of high-performance computing and visualization in these fields, compared to in earthquake engineering. This exposure may be both a benefit and a source of problems. On the positive side, deep experience and use of cyberinfrastructure by NBIC researchers may leave them more willing to consider and adopt innovative cyberinfrastructure. For example, labs that rely on advanced simulations and visualizations probably already have the hardware, software, and staff needed to support exploration of other cyberinfrastructure applications. On the negative side, though, overconfidence in technological solutions may result in under-appreciation of socio-technical factors that can influence the health and productivity of a collaboration. In particular, a recent NSF report by Cummings and Kiesler (2003) expresses doubt about the relative merit of some collaboration technologies versus explicit coordination practices in determining the success of geographically dispersed interdisciplinary research teams. That is, in many cases the establishment of norms and procedures for communication (even if this only involves a simple weekly meeting via phone conference) may be more critical than adoption of the latest technologies (e.g., immersive virtual environments, high-resolution videoconferencing, or ubiquitous computing).

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