Chapter 4

COLLABORATIVE VIRTUAL ENVIRONMENTS FOR SCIENTIFIC COLLABORATION: TECHNICAL AND ORGANIZATIONAL DESIGN FRAMEWORKS

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1. Introduction

Collaboration among scientists is human behavior that facilitates the sharing of meaning and completion of tasks with respect to a mutually shared scientific goal, and which takes place in social settings. Scientific collaboration across geographic distances began centuries ago, when scientists began utilizing postal and shipping services to exchange ideas as well as samples of plants and animals. More recently, collaborative virtual environments have brought new opportunities—and challenges—for scientific collaboration across distances. This chapter discusses two different challenges: designing collaborative virtual environment software tools, and designing organizational structures and practices to facilitate collaboration across geographical distances. To address the first challenge, a technical design framework that focuses on supporting situation awareness is proposed. The framework is based on research conducted by designing and evaluating a scientific collaboratory system, called the nanoManipulator Collaboratory, that allowed scientists to synchronously conduct experiments, collecting and analyzing data from an atomic force microscope. To address the second challenge, an organizational design framework based on a two-year case study of a distributed scientific organization is proposed. These two frameworks may be relevant for a wide range of distributed scientific work.

Today, many scientists often use multiple collaborative virtual environment (CVE) tools in various combinations to facilitate collaboration. Examples of tools that support synchronous collaboration are the telephone, video conferencing, instant messaging, chat, shared electronic whiteboards, virtual networked computing, shared access to scientific instruments, and

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shared applications, such as shared data visualization programs. Examples of tools that support asynchronous collaboration are e-mail, file transfer programs, WIKIs, electronic lab notebooks, project management tools, and listservs. Examples of tools that support individual access to information or a device include web pages that provide information about scientific research and outcomes, digital libraries and search programs that allow scientists to contribute, find and/or comment on scientific publications and data, and single-user remote access to scientific instrumentation and data.

No one tool today provides all features needed to fully support collaboration across distances during the entire scientific research life cycle. One challenge facing collaborative virtual environment tools is the ability to fully support shared situation awareness. Situation awareness has been defined as: "continuous extraction of environmental information, integration of this information with previous knowledge to form a coherent mental picture in directing further perception and anticipating future events" [1, p. 11].

It is a general sense of knowing about things that are happening in the immediate environment and includes having both an accurate understanding of the situation and the knowledge to respond appropriately as the situation evolves [2]. Based on previous research and our empirical studies, the types of information needed to develop and maintain situation awareness include contextual, task and process, and socio-emotional information. Research in virtual reality systems suggests that control, sensory, distraction and realism attributes of technology contribute to a sense of presence [3]. Consideration of these attributes with respect to contextual, task and process, and socio-emotional information provides insights to guide technical design decisions. The resulting framework was used when designing a CVE for scientific collaboration [4]. Results from a controlled experimental evaluation of the collaboratory system help illustrate the framework's utility.

It has long been known that organizational structures and practices influence technology adoption and use [e.g., 5, 6]. In addition to supporting situation awareness through technology, scientific collaboration in collaborative virtual environments may often require new organizational practices, especially when larger numbers of scientists need to collaborate across distances. Thus providing a framework to help design CVE tools should be augmented by a framework to help design organizational structures and practices in which the tools will, ideally, be embedded.

The organizational design framework to facilitate scientific collaboration proposed in this chapter is based on a two-year case study of a group of over 100 scientists. The scientists were primarily chemists and chemical engineers at four universities in the USA who were members of a research centre. They collaborated during all phases of the scientific process, including sharing knowledge during proposal development, scientific instrument design and construction, experiment design, data collection and analysis, and dissemination of results through papers and presentations. The case study began during the beginning stages of the centre and continued for 2 years. While conducting the case study, the author was a participant observer, having both complete and peripheral membership roles, collecting case study data and providing advice regarding collaboration technology and collaborative practices. Case study data included interviews, observations of meetings, sociometric surveys, and centre documents. These data were analyzed in the ethnographic and grounded theory traditions [7, 8], and the organizational design framework discussed in this chapter emerged from this analysis.

The organizational design framework introduces a new concept, called the conceptual organization. A conceptual organization has characteristics in common with traditional organizations, invisible colleges, collaboratories and virtual teams. However, it uniquely combines a management structure that is interwoven across other organizations, collaborative work practices based on collaboration technology, and use of integrative, economic and destructive organizational power. It has few employees in the traditional sense; most members are scientists who join the organization because they wish to contribute to its vision and goals. Benefits of a conceptual organization include its ability to discover solutions, quickly and effectively contributing to relevant dynamic knowledge bases and meeting diverse stakeholder needs with minimum capitalization and start-up costs [9].

This chapter first presents the technology design framework and, second, the organizational design framework. In presenting the technology design framework, the type of information needed to develop and maintain situation awareness in scientific collaboration, and features of technology to support the acquisition and sharing of these types of information are discussed. The application and evaluation of the framework in the context of the nanoManipulator collaboratory is also discussed. In presenting the organizational design framework, it is defined and compared to other organizational designs. Details regarding management structure, organizational membership, stakeholders, and collaborative knowledge management practices and use of technology are presented. Potential benefits and an evaluation of the organizational design framework are also presented. In sum, this chapter is a first effort to consider both technology and organizational design relevant for a wide range of future distributed scientific work.

2. A Technical Design Framework Focusing on Supporting Situation Awareness

2.1. Information to Develop and Maintain Situation Awareness

To develop an understanding of situation awareness in scientific collaborative work, 27 interviews with faculty, postdoctoral and graduate student scientists actively collaborating with one another were conducted. The average length of these interviews was 1.5 hours, with a minimum duration of an hour and a maximum duration of 2.75 hours. Study participants were also observed on nine occasions as they conducted experiments while working alone and with others. Analysis of the data and previous research suggest that situation awareness in scientific research collaboration requires several types of information, including contextual, task and process, and socio-emotional information. Distinguishing between these types of information facilitates our understanding of situation awareness and technical requirements for collaborative virtual environments.

C*ontextual information* is a broad sense of the context in which things are happening. Context can be defined as a "framework of meaning" [10, p. 8] or a "framework of understanding" [11, p. 52]. Contextual information includes information regarding norms of scientific practice, research goals, organizational culture and work environment. Contextual information can vary between collaborators, as one scientist described:

> The person that we were collaborating with was so much into "let's hurry up and publish this before so-and-so beats us and we won't get credit if they beat us." . . . And in the end, we found out the results weren't reproducible. I resisted all of the ideas this collaborator had to publish and in the end, it was the best thing I ever did because if we had published it we would have been wrong.

In a sense, contextual information includes the "rules of the game" and the "players in the game," and how to apply the rules. A scientist stated:

> I don't mind the political games necessary to see a few things come together . . . To get an idea . . . going . . . you have to get the blessings of various people.

When collaborators work face-to-face in the same context, they may already know most of the contextual information relevant to the situation, reducing the amount of contextual information that must be mediated by technology. However, when collaborators come from different contexts, they need to be able to discover differences and similarities in their understanding of the context, and possibly discuss or negotiate those differences.

Task and process information is defined as information about current and relevant task activities and work processes. It includes information about tasks currently being performed and who is performing them. It also includes information about what tasks should be performed, how they can be performed, who can perform them and where and when they can be performed. Task and process information assists an individual in understanding what collaborators are doing. It also assists in creating expectations regarding what collaborators might do. When two collaborators share an in-depth understanding of processes, they may appear to function as one with work responsibilities passing smoothly between them.

An individual may increase his or her task and process information by observing the sequence of tasks another person or group of people are performing and by discussing tasks and processes with them. As one scientist explained:

> Every now and then, she would look at us over the shoulder, I guess, and see how the experiment was going. And we talked with her too, every now and then.

Collaborators may have different task and process information, especially when collaborators come from different disciplines or have different expertise. For example, a scientist told us:

> [My collaborators] will generate data and then they'll go "we're going to run this through our computer software to see blah, blah, blah" . . . . I have no sense of what that involves. Is that a week of running a mainframe or is this something you put on there and click it and it comes back and says here's your picture?

Socio-emotional information is interpersonal information about collaborators. It includes information about their skills, work styles, approach to science, likes and dislikes, personality and emotional state. Several scientists discussed the important role socio-emotional information plays in their collaborative work:

> The best collaborations I have are the ones where the person I'm collaborating with thinks differently than I do . . . [this] is much more important than just getting experiments done more quickly.
>
> Interviewer: How do you judge whether somebody would be a good collaborator? What criteria do you use?
>
> Scientist: [The] kind of behavior they have towards other people. Do they behave ethically? Are they forthright? Do they openly discuss their research or are they secretive? Are they, it may sound silly, but do I like them? . . . Do I find them interesting people with sort of the same kind of values that I have towards the science?

Bales [12] and Nardi, Whittaker and Bradner [13] have shown that groups, working both face-to-face and remotely, communicate socio-emotional information. They show tension, tension release, antagonism, enthusiasm, solidarity, agreement, disagreement and empathy through a variety of mechanisms including jokes, questions, assertions and body language.

Contextual, process and task, and socio-emotional information can be interrelated. Information or a lack of information of one type can enhance or limit one's understanding of other information. For example, a scientist described collaborating with a professional and not understanding why the professional did not complete several tasks. The scientist lacked contextual and socio-emotional information about his collaborator, and could not understand the task and process information at hand:

> [He] is a clinician that deals with children who have this lethal disease . . . I just cannot seem to ever get him to come over or respond to e-mails . . . [is] he so inundated with clinical stuff that he can't carve out of his day what he needs to do the scientific? . . . I don't understand that . . . He can treat these patients for his whole career. Here's an opportunity to potentially bring a cure to them, and I don't understand why [he] can't say this is a priority.

This lack of contextual and socio-emotional information not only hindered the immediate collaboration but also future collaborations.

In summary, research suggests that situation awareness is built on a foundation of contextual, task and process, and socio-emotional information from previous situations. Poorly designed collaborative virtual environments that do not adequately support the development and maintenance of situation awareness may not only reduce the quality of current work but also of future work.

2.2. Technology Features to Enable Situation Awareness

When scientists collaborate face-to-face, they share an immediate environment and can develop situation awareness using contextual, process and task information gained through exploring, and experiencing, the (local) environment independently and/or collaboratively. However, when collaborating across distances, this exploration must occur across multiple environments (local and remote). The exploration of the remote environments is no longer a direct experience, but is mediated by technology. It is important to design systems that enable scientists to obtain contextual, task and process, and socio-emotional information about the remote environments independently and/or collaboratively.

Substituting "virtual" for "remote" in the previous sentence makes an obvious link to virtual reality (VR) technology. For CVE tools, the goal is to enable users to create and maintain situation awareness at the remote and local sites; in virtual reality technology, the goal is for users to create and maintain a sense of presence, or "being there" in a place other than where she is physically.

Virtual reality research suggests several attributes, or factors, of virtual reality systems that contribute to providing a sense of presence [3, 14–16]. More recent research [e.g., 17, 18] investigates the impact of these types of system attributes on task effectiveness.

Witmer and Singer [3] organize VR system attributes into four groups: control, sensory, distraction, and realism. *Control attributes* describe how well the user can interact with and change the virtual or remote environment. *Sensory attributes* are concerned with delivering information about the remote environment to the remote user, allowing the user to move through the remote

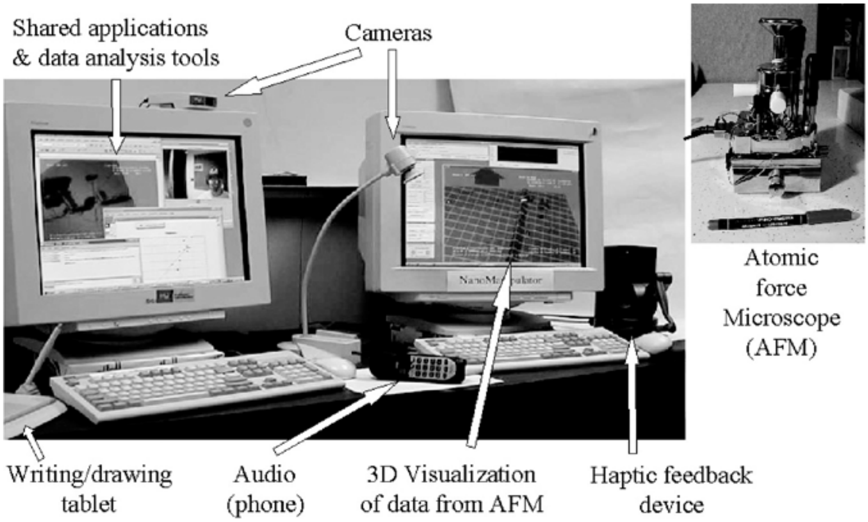

Figure 4-1. The nanoManipulator Collaboratory System.

environment and to actively and purposefully explore it. Just as systems must provide appropriate sensory stimuli, they must also minimize irrelevant external stimuli, or *distraction attributes*, that are not a part of, and particularly are inconsistent with, the stimuli from a remote environment. *Realism attributes* concern how much the remote world is like the natural world, i.e., the degree of consistency between the users' experience of the real world and their experience of the remote place. [Two of Witmer and Singer's realism attributes, meaningfulness of experience and separation anxiety/disorientation, are not dependent on technology design, but rather the application domain. Thus these factors are excluded from the design framework.]

We propose that, when designing a system, these attributes should be considered with respect to their ability to facilitate access to contextual task and process, and socio-emotional information. A table, with each row representing an attribute and each column representing a type of information, can be created to assist in this process (table 4-1). Each blank cell in the table represents something to consider during the design process.

2.3. *Applying the Framework*

2.3.1. *The nanoManipulator Collaboratory*

The framework was applied to the design of a CVE tool, the nanoManipulator collaboratory (figure 4-1). The goal of the nanoManipulator collaboratory is to provide shared remote access to a specialized scientific instrument, called a nanoManipulator (nM), and to support small groups of scientists as they

Table 4-1. Technical design framework.

		Information needed for situation awareness		
Technology attributes		**Contextual**	**Task & process**	**Socio-emotional**
Control	Degree of control			
	Immediacy of control			
	Anticipation			
	Mode of control			
	Physical environment modifiability			
Sensory	Modality			
	Environmental richness			
	Multimodal presentation			
	Consistency of multimodal presentation			
	Degree of movement perception			
	Active search			
Distraction	Isolation			
	Selective attention			
	Interface awareness			
Realism	Scene realism			
	Information consistent with objective world			

conduct research that utilizes the nM instrument. The single-user nM provides haptic and 3D visualization interfaces to a local (collocated) atomic force microscope (AFM), providing a natural scientist with the ability to interact directly with physical samples ranging in size from DNA to single cells [19, 20].

Hardware elements in the collaboratory system include two PCs. One PC is equipped with a Sensable Devices Phantom™ force-feedback device. This PC and its associated software provide haptic and 3D visualization interfaces to a local or remote atomic force microscope (AFM) and support collaborative manipulation and exploration of scientific data. Scientists can dynamically switch between working together in *shared* mode and working independently in *private* mode. In shared mode, remote, i.e., non-collocated, collaborators view and analyze the same (scientific) data. Mutual awareness is supported via multiple pointers, each showing the focus of attention and interaction state for one collaborator. Collaborators can perform almost all operations synchronously. Because of the risk of damage to an AFM, control of the microscope tip is explicitly passed between collaborators. In private mode, each collaborator can independently analyze the same or different data from stream files previously generated. When switching back to private from shared mode, collaborators return to the exact data they were previously using.

Another PC supports shared application functionality and video conferencing (via Microsoft NetMeeting™) and an electronic writing/drawing tablet. This PC allows collaborators to work together synchronously using a variety of domain-specific and off-the-shelf applications, including specialized data analysis, word processing and whiteboard applications. Video conferencing is supported by two cameras. One camera is mounted on a gooseneck stand so it can be pointed at the scientist's hands, sketches, or other physical artifacts scientists may use during experiments; the other is positioned to primarily capture a head and shoulders view of the user. Collaborators have software control of which camera view is broadcast from their site. A wireless telephone headset and speakerphone connected to a commercial telephone network provides high quality audio communications for collaborators.

2.3.2. Making Design Decisions

Following is a discussion of the technology attributes, and their importance to contextual, task and process, and socio-emotional information. Examples of design decisions that were made using the framework are provided. However, due to space limitations not all design decisions made based on the framework are presented here.

2.3.2.1. Control Attributes

Degree of control: Degree of control refers to the number of elements in the remote and local environments that the user can control and the extent of that control. The more control that collaborators have over the remote environment, the greater their situation awareness. The more control that collaborators have over the local environment, the easier it is to proactively provide contextual, task and process, or socio-emotional information to a remote collaborator. For example, controlling the focus of a local camera on task activities can help increase a remote collaborator's task and process information. The capability to reserve a system for an experiment and to learn about what experiments are planned will increase contextual information. Thus, the nM system was designed with these features.

Immediacy of control: Immediacy of control focuses on system responsiveness. The smaller the delay between initiating a system function (in the local or remote environment) and seeing the function's impact, the greater the sense of presence afforded. This enhances situation awareness by providing the means by which scientists can confirm actions. Software mechanisms that provide feedback as well as efficient algorithms and high network transmission speeds with low latency are typically needed to support this feature.

Anticipation: Anticipation is supported through media richness and consistency. When scientists conduct experiments while working face-to-face, they can recognize the activities being done and the status of those activities, and anticipate subsequent activities. For example, they can gather socio-emotional information, such as frustration and excitement, and anticipate responses, such as encouragement. This was addressed by providing multiple (high resolution and low latency) video camera views of the remote scientists.

Mode of control: In a collaborative system, a person may need to perform an action in one environment in order to cause a responding action in the other environment. Situation awareness is facilitated when that action is natural and similar across environments. For example, actions to change parameters for a data visualization should be exactly the same at all locations.

Physical environment modifiability: Situation awareness is enhanced when collaborators are able to modify the same artifacts in the remote environment as they could if co-located. For the nM system, this includes actions such as pushing, touching and/or modifying a sample during an experiment. In the stand-alone nM system, a scientist could perform these actions locally. The nM collaboratory system allows a scientist to perform the same actions when working remotely.

2.3.2.2. Sensory Attributes

Sensory modality: This attribute implies that systems should avoid forcing users to substitute one sensory mode for another. For example, although audio communication is closely related to collaborative task accomplishment, visual information is a strong source of socio-emotional, task and contextual knowledge [e.g., 21], and its absence in a collaborative virtual environment system would diminish the effectiveness of the system. In the nM system, haptic feedback is also provided when the microscope tip is pushed against a sample.

Environmental richness: Environmental richness implies that systems should gather and display a variety of contextual, task and process, and socio-emotional information at adequate resolution and update rates. This implies a need for high quality video connections that show facial expressions, gestures and local objects; high quality audio connections; and shared applications to increase the richness of the environment. In addition, a "window within a window" to view a collaborator's remote screen while still viewing your local screen may enhance contextual and process knowledge.

Multimodal presentation: When the senses of sight, hearing, smell and touch are stimulated in an integrated and complete manner, situation awareness may be increased. Our observations of scientists engaged in audio–video conferences reveal that the more artifacts brought into the discussion (such as shared drawing tools or shared documents), the more the participants become engaged in the discussions. In a collaborative virtual environment, such senses may include touch integrated with sight and sound. In the nM collaboratory system, haptic feedback is integrated with visual information coming from the visualization screen, contributing task and process knowledge.

Consistency of multimodal presentation: When visual, audio and haptic information are consistent and synchronized, people can more easily understand information. This can increase their confidence in, and use of, the information.

Time synchrony across data presentation modes is an important component of consistent multimodal presentation.

Degree of movement perception: This attribute focuses on self-motion within an environment. Zahorik and Jenison [22] believe that presence is enhanced when one understands the result of an action in an environment, whether that environment is virtual or real. Ideally, a collaborator should be able to clearly see and hear actions that occur in the remote location as a result of a local action.

Active search: Active search capabilities allow users to control sensors at remote locations to obtain desired information. When collaborators can modify sensors to effectively search the remote environment, their socio-emotional, task and process, and contextual information can increase. The scientists interviewed indicated that they would like to have multiple, pre-set video views of a remote collaborator's environment and the ability to modify those views dynamically using remotely controlled pan-tilt-zoom camera mounts and/or automatic tracking cameras. Previous research [e.g., 23, 24] has also illustrated the importance of providing the ability to switch between multiple camera views, as well as repositioning and refocusing cameras.

2.3.2.3. Distraction Attributes

Isolation: Isolation refers to the extent that the user is physically shielded from non-relevant, or distracting, information or activities in the local and remote environments. For example, devices that isolate a scientist from non-relevant aspects of the local environment can enhance his or her ability to gather and understand information from a remote environment. An example is the use of headphones to reduce ambient noise in the local environment so that a user may fully concentrate on the interaction with a remote collaborator. However, observations of scientists using desktop audio–video conferencing tools such as NetMeeting™ also show that they like to hear auxiliary conversations arising in the local and remote environment to increase their contextual situation awareness. A solution is to provide options regarding audio headsets and audio speakers.

Selective attention: This attribute focuses on the extent users ignore non-relevant information. For example, a collaborator's willingness to ignore distractions in the local environment should enhance their awareness of the remote environment. This is a psychological issue.

One method to capture and focus the attention of another person, particularly with respect to information on a monitor, is through pointing. We frequently observed scientists pointing to computer screens with their mouse pointer, fingers and pens to selectively focus a collaborator's attention. Thus, the nM system was designed to enable each scientist's pointer to be viewable by all collaborators.

Interface awareness: This attribute focuses on human–computer interface design. The human–computer interface for all types of information should be natural and easy to use. This has been previously proposed for all types of systems, and widely discussed in the human computer interaction literature [e.g., 25].

2.3.2.4. Realism Attributes

Scene realism: Scene realism, or the realistic rendering of the remote environment, addresses the validity of information from the remote environment used to develop situation awareness. Scene realism can be developed using real-world content, such as video, and simulated content, such as computer animation or graphical representations. It is affected by camera resolution, light sources, field of view, as well as the connectedness and continuity of information being presented [3]. Emerging technology, such as 3D telepresence, has the potential to increase scene realism.

Consistency of information with the natural world: Information about the remote environment provided by the system should be consistent with information learned through first-hand experiences. For example, if a scientist had previously visited a collaborator's lab then information about the lab, e.g., a floor plan, provided by the system should be consistent with the scientist's existing knowledge of the lab. Even when scientists have not had the opportunity to visit a collaborator's environment, they have expectations regarding that environment based on their previous experiences. Information provided by the system should be consistent with these expectations.

2.4. Evaluating the Design Framework

2.4.1. Controlled Experiment Evaluation

To investigate the validity and utility of the framework, we can evaluate the systems it helps to create. This is an indirect measure, and conclusions from the evaluation should be interpreted with caution.

The evaluation conducted was a repeated measures, or within-subjects, controlled experiment comparing working face-to-face and working remotely, with the order of conditions counterbalanced. The hypotheses followed previous research [e.g., 26] and would predict that task performance and perceptions of the system when using it to collaborate across distances would be lower because collaborators would lack the richness of collocation and face-to-face interaction, including multiple and redundant communication channels, implicit cues, and spatial co-references. This lack of richness is often thought to impair situation awareness and subsequently have a negative impact on task performance and perceptions of technology.

In the evaluation, twenty pairs of study participants (upper level undergraduate natural science students) conducted two realistic scientific research activities each requiring 2–3 hours to complete. Ten pairs of study participants worked face-to-face first and, on a different day, worked remotely (in different locations). Another ten pairs worked remotely first and, on a different day, face-to-face. When face-to-face, the participants shared a single nM collaboratory system; when collaborating remotely, each location was equipped with a complete nM collaboratory system.

The scientific research activities completed by the participants were designed in collaboration with natural scientists. The tasks were activities the scientists actually completed and documented during the course of their research. To complete the tasks the participants had to engage in the following activities typical of scientific research: operate the scientific equipment properly; capture and record data in their (electronic) notebook; perform analysis using scientific data analysis software applications and include the results of that analysis in their notebooks; draw conclusions, create hypotheses and support those hypotheses based on their data and analysis; and prepare a formal report of their work.

Task performance was measured through graded lab reports. The information participants were asked to provide in the reports mirrored the information scientists record in their lab notebooks. Each pair of study participants collaboratively created a lab report under each condition, generating a total of 40 lab reports; 20 created working remotely and 20 created working face-to-face. In addition, each participant was interviewed after each session. The post-interviews focused on participant's perceptions of the collaboratory system and their work patterns. The lab reports were graded blindly, and the post-interviews were analyzed using both open and axial coding [27]. During open coding, the interviews were read thoroughly and carefully and coding categories, or frames, were identified. During axial coding, the final step, all interviews were re-read and analyzed using the coding categories. Additional details regarding the experiment can be found in Sonnenwald *et al.* [28, 29].

2.5. Evaluation Results

The average lab report scores for the first task session were identical (70/100) for both the face-to-face and remote condition (table 4-2). Although a null result statistically, the comparable scores between the two conditions on the first task are encouraging.

Data analysis further indicated that in this study collaborating remotely first had a positive effect on the second, face-to-face interaction. Using a multivariate analysis of variance (MANOVA) test, the differences in scores for the face-to-face and remote conditions were not statistically significant at the

Table 4-2. Graded lab report statistics.

	Graded lab report scores (max. score = 100)									
	Collaborated FtF first ($n = 20$)					Collaborated remotely first ($n = 20$)				
Condition	**Mean**	**SD**	**Max**	**Min**	**Range**	**Mean**	**SD**	**Max**	**Min**	**Range**
Face-to-face	70.0	16.75	88	42	46	86.4	10.52	98	70	28
Remote	75.1	10.49	89	56	33	70.0	8.89	80	55	25

$p \leq 0.05$ level. However, when order is taken into account, participants who collaborated remotely first scored significantly higher on task 2 than did those who collaborated face-to-face first (df $= 1$, $F = 9.66$, $p < 0.01$). Due to available resources, we did not study the cases where participants completed the two task sessions under the same condition, e.g., both face-to-face or both remotely, and thus we are unable to eliminate the possible effect of task differences between the two sessions. However, these results suggest that the scientific tasks conducted remotely were of similar quality as those conducted face-to-face. The results further suggest that working remotely, each scientist having full access to the system at all times, may facilitate their learning about the system and scientific tasks at hand, and this possibly influenced subsequent scientific work in a positive way.

Participants' perceptions regarding control, sensory, distraction and realism attributes of the nM collaboratory system emerged from the analysis of the interview data. Participants requested several features the framework predicted would be important but were not implemented due to technical constraints; they reported negative perceptions of features that did not conform to the framework; and they reported positive perceptions regarding features the framework predicted would be important and which were implemented.

An example of features suggested by the framework and not implemented are automatic tracking or remotely controlled pan-tilt-zoom camera capabilities. These features were originally suggested when considering the active search (sensory) attribute. In post-interviews, several participants requested these features, e.g., one participant commented: "We didn't want to waste our time always adjusting the camera . . . have the camera follow you."

Similarly, a participant requested the capability to view a collaborator's remote screen while viewing their local screen, a feature suggested by the environmental richness (sensory) attribute. The participant explained:

> It would be good . . . if you're both in your private state [if] you could each see what the other's doing . . . if you have two different ideas of how to go about something, then you each can try it and see if you get to the same point without having to flip back and forth between [states.]

Study participants also reported negative perceptions of features that did not conform to the framework. For example, the consistency of multimodal presentation (sensory) attribute emerged as problematic for study participants. In particular, the video would "freeze" and be out of sync with the audio. Participants commented: "The video window froze and that was slightly aggravating." And, "[the video] kept stopping . . . his picture would freeze . . . the audio would be far ahead of where the video was." Other participants commented: "[The video] was extremely helpful . . . I couldn't really describe [a scientific phenomenon] as well as I could just move my hands . . . in front of the camera." Also, "I liked the video conferencing . . . I like seeing people as I interact with them and they react."

Thus the video had utility, but the multimodal presentation of the video and audio was not effective. This particular problem can be addressed through improvements in networking infrastructure and algorithms that provide faster and more reliable video transmission and coding and decoding. These types of issues are typically outside the scope of any single collaborative virtual environment, yet they impact users' perceptions of the environment.

Participants also reported positive perceptions of features that were suggested by the framework and implemented. This was particularly evident with respect to the mode of control attribute. In the nM visualization software component, all users can execute system functions concurrently. Thus the model of control is identical when working individually and collaboratively. Participants commented: "The best thing was . . . the ability to work on the same thing at the same time with the nM." And, "[we] never fought over the nM because . . . both of us [could] use it at the same time."

In comparison, the mode of control differed when using the off-the-shelf shared application software, NetMeeting™. In NetMeeting users were required to explicitly take control of a shared application by double-clicking on the application window. One participant explained:

> [It] became exceedingly frustrating . . . to share control . . . When I wanted to do something and my partner wanted to do something at the same time, we . . . went back and forth double-clicking to gain control, and . . . it took us a few seconds to even acknowledge that. Essentially . . . we were fighting over control.

Task performance as measured by graded lab reports and perceptions of the system as discussed in post-interviews help demonstrate the appropriateness of the features suggested by the framework and provide some insights regarding the validity and utility of the framework.

2.6. Limitations of the Technical Design Framework

It may not be possible or necessary for a CVE to equally support the acquisition and dissemination of contextual, task and process, and socio-emotional information. Emphasizing one or two types of information may help prioritize design and implementation decisions. The framework presented in this chapter identifies types of information to support situation awareness but it does not prioritize them. For example, due to technical and budget constraints, some design decisions suggested by the framework could not be implemented.

Furthermore, it is not known if the list of attributes in the framework is exhaustive. Additional categories of attributes and additional attributes within categories may emerge as technology and our understanding of human information processing evolves. Future research is needed to investigate guidelines for prioritization.

3. An Organizational Design Framework

As mentioned earlier, technology adoption and use is not solely influenced by features of the technology but also by organizational structures and practices. These organizational factors become increasingly complex when a large group of scientists needs to collaborate across distances, not only by sharing data and instruments but also by actively discussing ideas, identifying problems and solutions. Increasingly scientific problems require such collaboration among groups of scientists, many of who often work in different organizations, geographic locations and disciplines. How can such scientific research be best organized?

To address this issue, a two-year field study of a large, distributed group of scientists was conducted. Analysis of organizational documentation, sociometric surveys, interviews and observation data suggests that a new type of research and development (R&D) organization, called the conceptual organization, is one solution [9, 30].

3.1. Research Methodology

The conceptual organization framework is based on an in-depth two-year case study of an R&D centre in the US. Initially, the Centre had approximately 30 faculty scientists and 82 students and postdoctoral fellows, and three full-time staff members physically located at four different universities in the US. Membership has changed over the years, and after 3 years there were approximately 45 faculty scientists, 70 students and postdoctoral fellows and three full-time staff members located at five US universities. The R&D centre was first funded late 1999, with a five-year $15 million dollar commitment from a national funding agency with matching support from several participating universities, corporations and a non-profit foundation.

The case study began during the beginning stages of the centre and continued for 2 years. While conducting the case study, the author was a participant observer, having both complete and peripheral membership roles. As a complete member, the author had functional, in addition to research, roles in the research setting. The author served as the Centre Coordinator of Social Science Research Efforts and a member of the Centre management team. She actively participated in the management meetings, contributing to discussions and participating in decision-making. However, when the meetings and decision-making focused on research in natural science and engineering topics, topics not in the author's areas of expertise, she assumed the role of a peripheral member. She observed the activity, taking notes and audio-recordings, and occasionally discussed events and outcomes with meeting participants but she did not actively participate in the discussions and decision-making. Seventy-three management team meetings were held during the two-year study, and the author observed and participated in these meeting. The author was also a peripheral member participant in centre-wide weekly research meetings, generally observing discussions and only completely participating when discussions regarding collaboration and collaboration technology took place. Centre members were made aware of the author's roles.

Observation data included transcribed audio-recordings of meetings, video-recordings of videoconferences, meeting and centre documentation and researcher notes. These data were analyzed in the ethnographic and grounded theory traditions [7, 8]. Using semantic content analysis [31] patterns and meanings behind the observations were sought. That is, a theoretical framework was not imposed on the data a priori but rather the data were thoroughly analyzed for patterns within the data and the meaning of those patterns. Results were subsequently shared with several centre members (informants) and their feedback was incorporated.

Two sociometric surveys were also conducted to provide quantitative data regarding collaboration within the centre. The surveys investigated current collaboration among centre members, and took place approximately 12 and 24 months after the centre was established. Response rates for the two surveys were 68% and 73%, respectively. The data were analyzed using sociometric techniques [32] to investigate the number of collaborations among scientists and students, collaborations across universities and changes in collaborations over time. To further investigate collaboration and organization effectiveness, co-authorship of journal publications and research funding data over 3.5 years was collected and analyzed.

Although the technology used in the case study was not a CVE in the strictest sense, components of the technology used had features, such as synchronous applications and voice over IP, that overlap with CVEs. Furthermore, we know that issues regarding the use of CVEs are often organizational in nature. Getting people to participate in CVEs, sharing information equally, are typically more serious and harder to resolve than technical issues, and thus this case study has relevance for CVEs.

3.2. The Conceptual Organization

3.2.1. Definition of a Conceptual Organization

A conceptual organization is a new type of research and development (R&D) organization that has emerged to facilitate collaboration among large groups of geographically distributed scientists in order to tackle large, complex and challenging problems of national and global importance. Its purpose is to discover solutions, quickly and effectively contributing to relevant dynamic knowledge bases and meeting diverse stakeholder needs with minimum capitalization and start-up costs. It has a conceptual organizational structure in addition to a physical structure, both of which are interwoven across other external organizational structures. It has few employees in the traditional sense; most members are scientists who join the organization because they wish to contribute to its vision and goals. These scientists are typically employed full time by universities or an R&D laboratory, and have a part-time affiliation with the conceptual organization. The conceptual organization provides a management structure and organizational practices that facilitate collaboration among members working towards its vision and goals. The power of the conceptual organization is primarily integrative in nature.

3.2.2. Synthesis of Multiple Organizational Forms

The conceptual organization has characteristics, or features, in common with traditional organizations, invisible colleges, scientific collaboratories and virtual teams. For example, similar to traditional R&D organizations, conceptual organizations need physical space, including offices for researchers and staff as well as laboratories to house specialized scientific equipment and conduct scientific experiments. For the conceptual organization, however, these needs are often negotiated and met through relationships with other organizations, such as universities, with which their members are affiliated. Conceptual organizations and traditional R&D organizations also have aspects of management in common, such as a management team that includes directors and an external advisory board who reviews the organization's progress. However, as discussed below the management structure of a conceptual organization has a more diversified membership.

Similar to invisible colleges [33], members elect and are selected to participate in a conceptual organization based on their knowledge and expertise. However, in a conceptual organization the selection and participation process is more formal than in an invisible college. Participation in an invisible college is often a matter of knowing its members and thereby gaining entry and acceptance through interaction with them. In a conceptual organization, there is a formal invitation or application process in addition to the informal process.

This is because conceptual organizations typically provide research funding or other costly resources for its members whereas invisible colleges do not.

A scientific collaboratory is a laboratory without walls [34]. A conceptual organization has many characteristics in common with a collaboratory, e.g., a conceptual organization may provide remote (electronic) access to data sources, artifacts, tools and experts. However, the primary goal of a conceptual organization is to address a specific, complex and challenging research issue, while the primary goal of a typical collaboratory is to provide remote access to data sources, artifacts, tools and experts to facilitate scientists' individual research initiatives. The nature and emphasis of these goals are slightly different, although the implementation of these may have aspects in common. For example, a conceptual organization and collaboratory may use similar technology, such as a CVE, to facilitate collaboration across geographic distances. However, a conceptual organization focuses on, and is evaluated with respect to, the results of its research and educational activities; whereas a collaboratory typically focuses on, and is evaluated with respect to, the utilization of its resources.

Virtual teams are groups of individuals who may not meet face-to-face but work together towards a common goal at a distance. Often the team is brought together to address a specific goal and disbanded after that goal is met or when the goal is no longer deemed important [35]. In corporate settings, these teams may cross organizational boundaries and include individuals from different corporations. A conceptual organization may encourage teams to form to address goals related to the vision, and some of these teams may be virtual. For example, a virtual team could be formed to help coordinate all proposed research efforts going on in two locations on a particular topic. However, a virtual team is more limited in scope and size than a conceptual organization.

Thus, a conceptual organization has characteristics in common with traditional organizations, invisible colleges, collaboratories and virtual teams. However, it also appears to be a unique organizational form. As described below, its management structure, use of organizational power, types of stakeholders, benefits and challenges combine to represent a new organizational form that facilitates collaboration across organizations and geographic distances.

3.3. Description of a Conceptual Organization

As discussed previously, the conceptual organization has characteristics in common with other types of R&D organizations, and it employs an innovative combination of organizational practices found in them. These organizational practices are presented in this section to provide a detailed portrayal of a conceptual organization.

3.3.1. *Management Structure and Organizational Membership*

The management structure of a conceptual organization includes a director who sets the overall prioritization for the centre and is responsible for leading the strategic vision and planning process. In addition, the director takes a lead in organizing the research as well as the dissemination of the research in "real time" by organizing the centre-wide group meetings. As director, this person also leads the interactions with the external stakeholder groups, such as the national funding agency, an external advisory board, affiliate university administrations and the media. In addition to these responsibilities, the director teaches and conducts research.

A conceptual organization typically also has a co-director and a deputy director. The co-director's primary responsibility is financial leadership and leadership in strategic planning. The co-director is also the leader of the external industrial affiliates group and conducts research. In the organization studied, the co-director was a close research collaborator to the director and was essentially interchangeable with the director in many functions. The deputy director is a position created explicitly to help with the numerous administration requirements associated with the centre. The deputy director plays an organizational lead position for the strategic plan and its implementation and accountability. The deputy director is also responsible for leading the generation of the annual report and overall compliance with the cooperative agreement between the universities and the funding agency. In a supporting role, the deputy director also assists with the numerous outreach programs and represents the organization at external venues on numerous occasions.

Thus the directors share in the responsibility of creating and communicating the vision of the organization, as well as administrative tasks. This helps to alleviate common burnout, which often leads to a degradation of management's ability to create and maintain a strategic vision and vibrant research program.

To further broaden participation in organization management, the directors are assisted by a management team that includes a site coordinator for each participating university, a coordinator of collaborative efforts, a higher education outreach coordinator, a kindergarten through 12th grade (K-12) education outreach coordinator, a scientific program committee and an office manager. Site coordinators handle location-specific administrative issues, ranging from reserving a videoconference room for weekly meetings to distributing allocated budget funds. The coordinator of collaborative efforts manages socio-technical activities to support collaboration within the centre and coordinates social science research done in the centre. The higher education and K-12 outreach coordinators oversee the educational outreach activities done by centre members and their staff. The scientific program committee provides input regarding natural science research and development.

The participation of site coordinators, i.e., representatives from each physical location, provides ongoing dialog about challenges, progress, perceptions and ways of working at each location. It is a way to interweave the conceptual organization among multiple physical locations and the external organizations at those locations. It eliminates the need for individual scientists to take sole responsibility of coordination and cooperation between their local and remote organizations (in this case, between their local university and a conceptual organization). It also facilitates learning about different ways of working and collaborative problem solving when members from different locations suggest how practices at their location may solve problems at other locations. For example, one team member suggested a possible solution to a colleague at a different location:

> Another thing you can do . . . to magnify your undergraduate help is that you can have undergraduates getting paid for a certain amount of their research but then getting credit for a certain amount, so that you only have to pay for part of it . . . We pay [our undergraduate students], but . . . we also want them to take two semesters of [research credits].

Similarly, the participation of K-12 outreach, social science, minority and technical program coordinators on the management facilitated coordination and collaboration among these diverse domains.

Scientists and students in a conceptual organization typically have a primary affiliation with the university at which they are physically located. They become members by proposing research projects and activities that would help the conceptual organization achieve its vision, mission and goals. Faculty scientists (current and potential members) may submit proposals that outline research projects that, ideally, support the conceptual organization's vision and mission. The proposals are typically reviewed and discussed by members of the conceptual organization's management team. Primary evaluation criteria may include: fit to strategic plan, potential impact and scientific merit. Secondary evaluation criteria may include: collaboration plan, K-12 outreach record and plan, and outside funds attracted.

3.3.2. Power within the Conceptual Organization

Boulding [36] describes three types of organizational power: destructive, economic and integrative. Destructive power, the power to destroy things, can be used for carrying out a threat and as a prelude to production, where things are destroyed or altered to make way for production. An example of destructive organizational power is the firing of employees who are seen as resisting change in an organization. Economic power is used in all organizations. It involves the creation and acquisition of economic goods, including intellectual property, through production, exchange, taxation or theft. Integrative power involves the capacity to build organizations, inspire loyalty, to bind people together and to develop legitimacy. It has a productive and destructive aspect. In a negative sense it can create enemies and alienate people. All organizations have some integrative power or they could not survive. Some, however, rely on integrative power more than others; these include religious organizations, political movements, volunteer organizations and clubs. Their existence and growth are influenced by the extent to which the objectives of these organizations match the dynamic value structures within a larger population.

The conceptual organization uses a combination of integrative, economic and destructive power; however, its primary source of power appears to be integrative. It solicits funding and participation based on its vision, mission and goals. That is, it attracts funding from corporations, government agencies and other institutions by convincing them that its vision, mission and goals are valid and achievable. A conceptual organization cannot promise an economic return on investment although it may offer some hope to funding corporations that it will effectively educate students who may become future employees and generate patents and other knowledge that may have economic value. Conceptual organizations attract scientists and students similarly, i.e., by convincing them that the organization's vision, mission and goals are exciting and participation in the organization can provide great personal satisfaction.

A conceptual organization may use integrative power in developing its vision, mission and goals. For example, when describing the process of developing a vision, the executive director commented:

> It's intended to be an inclusive process. We've included most of the [faculty] here in the centre in this process. Certainly our external advisory board had a part to play. It's iterative . . . We made our first draft of the vision, mission and goals, and reviewed those with [the faculty] . . . We then reviewed those with [industrial partners] and with our external advisory board. We got their input, what they thought we should be doing in a strategic direction . . . we integrated these comments.

A conceptual organization augments integrative power with economic power, providing some funding to scientists and students. For example, in the conceptual organization studied scientists typically receive one month's summer salary, funding for one graduate student or 50% funding for a postdoctoral fellow, up to $4,000.00 for supplies, and $500 for travel. However, these amounts are by themselves not necessarily sufficient to attract and retain high-caliber scientists who often receive government and corporate funding in much larger amounts. A vision that scientists believe in is also required.

As in any organization, destructive power is used when members do not meet expectations or keep commitments. This may be implemented in the conceptual organization through decisions not to continue funding scientists whose work is judged not in alignment with the conceptual organization's vision, mission and goals. For example, during a meeting deciding funding, participants supported and criticized proposals using comments such as: “This [proposed project] was not the lowest on my list, but I really miss the connection to objectives, goals, mission, etc. here. I could not see where this is going to lead.”

These decisions, however, should be reached through integrative power. In the conceptual organization studied, the review was done collaboratively with the scientific program committee, consisting of a lead scientist from each location and the conceptual organization’s director, co-director and deputy director. This group also developed the call for proposals. The call included the conceptual organization’s vision, mission, goals and critical needs as well as the proposal process and evaluation criteria. The process included a preliminary proposal in which faculty were requested to provide a title and a brief statement of research objectives (six to eight lines in length.) The committee provided feedback to the faculty on their preliminary proposals. The preliminary proposals were: “A mechanism for earlier dialogue . . . The benefits are . . . to attempt to avoid excess overlap [between projects]; . . . to identify opportunities for collaboration . . . not only within a given university, but also between universities; . . . to identify any unmet needs.”

Thus, through interaction with faculty and collaboration among management team members, integrative and destructive powers were used.

3.3.3. Stakeholders of a Conceptual Organization

All organizations, including conceptual organizations, have stakeholders, i.e., individuals or organizations who have a stake in a given organization’s success. The case study suggests that stakeholders in a conceptual organization include society, scientific disciplines or paradigms, government funding agencies, businesses and academic institutions.

It appears that society is a primary stakeholder of a conceptual organization’s vision in that society legitimizes the government, corporations and institutions that ultimately fund the conceptual organization. For example, the vision of the conceptual organization in the case study supports green chemistry. Green chemistry in general is currently valued by American society. The need to develop new processes and products that do not pollute the environment are recognized as important throughout American society. Even with this general support, results and justification of the government’s investment is needed. For example, the conceptual organization directors have made presentations to the US Congress and met with Senators and Representatives. These activities are necessary in part because if citizens in democratic societies do not approve of a conceptual organization’s goal, they may organize to limit its funding.

Scientific disciplines are also stakeholders interested in the mission of a conceptual organization. Disciplines typically wish to see knowledge created and students trained in certain scientific areas. This is motivated by collectively held belief systems and yearning for self-preservation and perpetuation of a discipline or scientific paradigm [37], and the mission of a conceptual organization has the potential to contribute to the growth of knowledge in particular scientific disciplines and/or paradigms.

Government funding agencies, businesses and academic institutions are stakeholders who are typically interested in a conceptual organization's vision, mission and goals. For these stakeholders the vision and mission is necessary but not necessarily sufficient. They are also interested in how the vision and mission will be achieved and measured, i.e., the organization's goals. They are typically concerned about justifying their investment in the conceptual organization to their stakeholders, e.g., federal and state governments, and upper management. For example, the conceptual organization studied produced a 226-page report detailing its activities and accomplishments during the preceding 12 months to help justify its government funding. Quantitative measures reported included publications, presentations, patents, supplemental funding, students supported, students graduated, K-12 and minority students reached through outreach activities, and K-12 teachers reached.

Businesses do not appear to seek a return on investment from a conceptual organization in the same way when investing in a company because they anticipate other benefits. For example, in a survey of 249 corporations who participated in industrial-university research centers, Gray, Lindblad and Rudolph [38] found that professional networking, including enhanced student recruitment and improved cooperation with scientists, was the primary factor influencing corporate decisions to maintain their relationship with and support of an industry-academic centre. Quality of the research and technical benefits, such as commercialization impact, were not found to impact corporate support of the centers. A conceptual organization should hold bi-annual or annual meetings that showcase students for its external industrial affiliates group.

3.3.4. Knowledge Management: Interaction among Members

A conceptual organization must utilize CVE and other technology as mechanisms to support its vision and mission, or incur expensive monetary and temporal travel costs. For example, in the conceptual organization studied video conferencing and shared electronic whiteboards were used for organization-wide meetings, weekly centre-wide research meetings, and weekly project team meetings. Organization-wide meetings were held relatively infrequently (e.g. once every 6–8 months); these meetings included all members at all universities and have been used to share information among all members. For example, a conceptual organization-wide meeting was held that introduced the organization's mission, management structure and conceptual organization-wide activities several months after the organization was established.

In the organization studied, centre-wide research meetings were held weekly; all members were invited to attend these meetings, however, students were required to attend. Each meeting typically lasted 1.5–2 hours, and at each university participating in the centre, small groups of 2–25 students and faculty would be in attendance. During the meetings, students and postdoctoral fellows presented and discussed their work at least once per year, responding to questions and comments from other participants.

The format and technology used in these meetings evolved over time. New social protocols, including the introduction of sharing interpersonal information, were introduced to compensate for constraints imposed by the technology. New operations protocols to help reduce technical problems were developed and implemented working with centre members and technical staff [39].

The video-conference technology used for centre-wide meetings included: a large electronic whiteboard and PC running shared application software to display slides and create and capture notes in real time; two large (120 inch) display screens that showed an overview shot of participants in each location and multiple views of one or several individuals in each location; microphones for each participant to capture and broadcast anything they wish to say; stereo audio speakers to enable each participant to clearly hear what is said by others; multiple cameras at each location to capture views of the audience, especially the person currently speaking; and a combination of networks such as ISDN/H.320, local state government analog video network, and video over IP (internet protocol) and required muxes. The technology used for project team meetings was similar but smaller in scale, e.g., it included the large electronic whiteboard but not the large display screens. Although these are not CVE tools in the strict sense, there are many similarities with CVEs if used for large meetings.

Initially, the technology increased the formality of the meetings. Students were concerned about using technology that was new to them and discussing their work with such a large audience; thus they initially prepared more before the meetings and gave formal talks. The initial meetings were also plagued with technical problems and this frustrated many participants. However, after these issues were resolved through new social and technical protocols [39], the meetings became very interactive and increased members' awareness of one another's work. In particular, students received important feedback on their work, and faculty learned about ongoing research efforts. The latter was achieved through minimal effort. If a presentation and discussion was not relevant to a member's work, the member could unobtrusively do other work during the discussion. However, problems originating from a lack of trust among members can still occur and need to be managed. Discussions regarding this issue can be found in Sonnenwald [30].

3.4. Benefits of a Conceptual Organization

A benefit of a conceptual organization is its ability to contribute to and respond to dynamic needs for new knowledge. This is achieved through multiple mechanisms. One such mechanism used is the dynamic incorporation of scientific experts in emerging relevant areas. For example, the centre has a call for proposals on a two-year cycle. This enables the incorporation of new scientists and research topics every other year. Another mechanism that supports the dynamic incorporation of scientific experts and emerging relevant areas is “seed funding” which is available on a yearly basis. In other R&D organizations, such efforts have been called “skunk works” but these are limited to existing organizational members and are hidden from other parts of the organization. In conceptual organizations, such efforts can be proposed by existing or potential members. These efforts are not hidden from view, and may be fully integrated in the organization through activities such as review meetings. Thus, all results are shared among centre members so everyone can learn from them. A third mechanism is matching funding. Scientists can use funding from the conceptual organization as matching funds in other grant proposals that may include additional scientists and students as well as emerging relevant research topics. This brings additional resources to bear in addressing the vision, mission and goals of the conceptual organization.

An additional benefit provided by the conceptual organization appears to be lower capitalization or start-up costs. These lower costs are achieved through the re-use of existing physical spaces and equipment at the associated universities and organizations, limited term and partial commitment to members and the inclusion of students and postdoctoral fellows. A conceptual organization may rely on space and equipment at its associated universities to support the research being conducted by its members, scientists and students. In return, the organization may purchase new equipment that scientists and students at the universities but not associated with the conceptual organization may also access. The conceptual organization also provides funding to enable students to attend the universities. A limited (2 or 1 year) and partial commitment to scientists (only one month summer salary is typically provided to scientists) further reduces the start-up costs of a conceptual organization. Of course, the inclusion of students and postdoctoral fellows who are by definition limited term also reduces or limits start-up costs for it as well.

A further benefit of a conceptual organization may be found in its ability to meet diverse stakeholders’ and members’ needs. As discussed previously, a conceptual organization’s stakeholders can include society, scientific disciplines or paradigms, government funding agencies, corporations and academic institutions. This diverse and important set is an outgrowth of a variety of political, social and economic forces; no other type of R&D entity has a similar broad set of stakeholders. Furthermore, the infrastructure at academic institutions is typically based on department and disciplinary boundaries with fierce competition for resources, authority and territory [40]. This is often a barrier when addressing large complex and challenging problems of national and global importance where the best scientists irrespective of discipline, department or institution affiliation are required.

3.5. Evaluation of the Conceptual Organizational Framework

To evaluate the effectiveness of the conceptual organizational design framework, data regarding collaborations, co-authorship, and funding in the organization studied were collected and analyzed.

As previously mentioned, two sociometric surveys were conducted asking organization members to identify other members they were currently collaborating with. The first survey took place 1 year after the conceptual organization was established; the second took place 1 year later. The number of collaborations reported among faculty scientists increased from an average of 2.37 per scientist to 3.36 per scientist; a 41.7% increase from year 1 to year 2 (see table 4-3.) A larger increase was seen in the growth of collaborations among scientists at different universities than among scientists at the same university (61.1% versus 27.6%). This indicates that collaboration among scientists within the organization developed across universities (and distances).

Another effectiveness measure is co-authorship of journal publications. Table 4-4 shows the number of co-authored and single-authored journal articles published over 3.5 years. Not surprisingly, there were fewer articles published in year 1 due to the start-up time lag that naturally occurs in research. From year 2 on, there were more articles published by co-authors from different universities than published by authors at the same university or published by single authors. On average, 48% of the total articles published were by authors from different universities. These data further suggest that the organizational structure and practices within the conceptual organization studied facilitated collaboration.

A third measure of research effectiveness is the ability to attract funding. The centre studied was initially successful in obtaining research funding from a government agency. Over the next 3 years, the organization also procured $1 million per year in funding from the participating universities, $1 million per year from other sources, e.g., corporations and non-profit organizations. The participating faculty also procured an additional 128 grants for a total of $47 million. These data combined with data regarding the quantity of self-reported collaborations and co-authorship trends provide insights regarding the utility of the conceptual organizational framework.

Table 4-3. Reported collaborations in the centre.

	Collaborations						
	After 1 year		**After 2 years**		**Change between 1st and 2nd year**		
Type of collaboration	**Total**	**Per person**	**Total**	**Per person**	**Total**	**Per person**	**% change per person**
Among all scientists	71	2.37	148	3.36	+77	+0.99	+41.7
Among scientists at the same university	37	1.23	69	1.57	+32	+0.34	+27.6
Among scientists at different universities	34	1.13	80	1.82	+44	+0.69	+61.1
Among all scientists & students	191	1.71	223	1.96	+32	+0.25	+14.6
Among scientists & students at the same university	42	0.38	68	0.60	+26	+0.22	+57.9
Among scientists & students at different universities	139	1.24	155	1.36	+16	+0.12	+9.7

Table 4-4. Co-authorship of journal articles by centre members.

	Co-authors from						
	Same university		**Different universities**		**Single author**		
Publication year	#	%	#	%	#	%	**Total**
Year 1	3	75	1	25	0	0	4
Year 2	2	14	10	71	2	14	14
Year 3	10	34	12	41	7	24	29
First 6 months of year 4	8*	28	16**	55	5	17	29
Yearly averages	*38*		*48*		*14*		

* Includes 3 published and 5 submitted.
** Includes 5 published and 11 submitted.

3.6. Challenges for a Conceptual Organization

One challenge for a conceptual organization involves reconciliation with existing academic and disciplinary cultures. As discussed, a conceptual organization is embedded within existing academic and disciplinary cultures; its members must also be active and accepted participants in their university departments and disciplines. Conflict among these can emerge with respect to job performance evaluation and career paths.

For example, one critical job performance evaluation in research universities in the US occurs when an assistant professor is reviewed for tenure and promotion to associate professor. Typically, an assistant professor is required to leave the university where they are employed if tenure is not granted. Decisions regarding tenure are initially decided by colleagues in the same department and discipline (who may not be members of the conceptual organization). These decisions are based on several evaluation criteria, including: an individual's ability to establish a research agenda or vision; an individual's record of research funding; and recognition of the individual's research contributions in the larger academic community. All of these may be negatively perceived in cases where an assistant professor is a member of a conceptual organization. For example, an assistant professor's research agenda or vision may be perceived by colleagues as lacking originality or insight because it is linked to the conceptual organization's vision, which would not be credited to the assistant professor. Research funding through a conceptual organization does not have the same requirements or review process as found with national and other funding agencies, and thus may not be as highly valued. Furthermore, a conceptual organization's vision may require expertise from multiple disciplines. When an assistant professor collaborates with others not in the same discipline, it can limit the opportunity for colleagues in her or his discipline to learn about and understand the assistant professor's research contributions. This lack of knowledge or understanding may also contribute to a negative evaluation. Thus, the tenure evaluation process may discourage or even conclude an assistant professors' participation in a conceptual organization, with negative consequences for both the assistant professor and conceptual organization.

Associate and full professors must also be active participants in their local university departments and discipline. Activities encouraged by a conceptual organization, e.g., participation in weekly video-conference meetings providing students at other universities feedback on their research and helping a colleague at another university set up research lab equipment, may not be encouraged or valued by one's local university department and colleagues in the same discipline. Individuals have time constraints and, as a result, a faculty member may find they must make difficult choices between contributing to a local department and their career versus contributing to a conceptual organization.

4. Discussion

Scientific collaboration is complex, yet critical to addressing complex problems that cannot be solved by any one individual, discipline or organization. Collaborative virtual environments can facilitate scientific collaboration but care should be taken when designing both the technology and the organization for which the technology is intended. Traditionally technology design occurs independently of organizational design. Indeed, research in these areas also typically occurs in different disciplines, e.g., computer science and business. However, in practice technology and organizational design are interdependent; each influences and helps shape the other. This chapter is a first effort to consider both technology and organizational design for scientific collaboration.

To address the technical design challenge, we built on previous research in situation awareness as well as interviews and observations of scientists to illuminate the complexity of situation awareness in scientific research and to propose that contextual, task and process, and socio-emotional information is needed to create and maintain situation awareness. Research in virtual reality systems suggests control, sensory, distraction and realism attributes of technology contribute to a sense of presence. We suggest that consideration of these attributes with respect to contextual, task and process, and socio-emotional information provides insights to guide design decisions.

The framework was used to guide decisions regarding technology to support situation awareness for the nM collaboratory system. As a result, the nM collaboratory system includes: consistent shared and private work modes, or spaces; the ability to dynamically switch between those shared and private work modes; the ability to customize an individual view of a shared work space; and multiple pointers that indicate each collaborator's focus of attention, interaction mode and actions simultaneously to all remote sites when in shared mode. The results of a repeated measures, or within-subjects, controlled experimental evaluation of the nM collaboratory system help illustrate the validity and utility of the framework, yet should be interpreted with caution because they are indirect measures of validity and utility.

In addition to considering new frameworks to support technology design, it is important to consider organization design, i.e., how the structure and practices of an organization can be designed to facilitate scientific collaboration. To address the organizational design challenge, we built on previous research as well as an in-depth two-year case study of a successful group of approximately

100 geographically distributed scientists. The resulting framework is the conceptual organization. A conceptual organization should have a long-term vision that addresses large complex and challenging problems of national and global importance. Its goal is to works towards this vision, quickly and effectively contributing to relevant dynamic knowledge bases and meeting diverse stakeholder needs with minimum capitalization and start-up costs. To achieve this, it has an explicit conceptual organizational structure in addition to a physical structure, both of which are interwoven across other external organizational and physical structures. Conceptual organizations engage scientists through the appeal of their vision and management structure and practices that encourage and facilitate collaboration. Challenges for conceptual organizations may arise due to conflicts with traditional norms and practices embedded in university and R&D settings. Social network, co-authorship publication and funding data from the case study setting provide initial evidence of the effectiveness of the conceptual organizational framework.

Additional research, utilizing both the technical and organizational design frameworks in a single setting, would provide increased insight regarding the interplay between the frameworks. However, seldom do researchers get such opportunities; our disciplinary, institutional and funding structures today do not encourage such efforts. Yet as we move towards greater understanding of both technical and social aspects of collaborative virtual environments perhaps such new opportunities may emerge. In the meantime, the technical design framework can help guide the development of CVE technology, in particular its ability to support the creation and maintenance of situation awareness across distances. The organizational design framework can help guide the design of research organizations that are geographically distributed. Both frameworks offer new ways of facilitating distributed scientific collaboration.

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