13

Levels of Expertise and Trading Zones: Combining Cognitive and Social Approaches to Technology Studies

Michael E. Gorman
University of Virginia

Nancy Nersessian's chapter (chap. 2) at the beginning of this volume, highlights the historic tensions between cognitive and sociological approaches to the study of scientific thinking. She looks for a synthesis in the area of situated cognition, where thinking is considered an activity that occurs in the environment as well as in the brain (Gorman, 1997).

Recently, Harry Collins, one of the originators of the social constructivist position in science studies, has advocated a new approach that holds promise for an integration between cognitive and social approaches. He and his colleague Robert Evans discuss two waves, or movements, in science studies, and propose a third.[1] During the first wave, social scientists "generally aimed at understanding, explaining and effectively reinforcing the success of the sciences" and "a good scientific training was seen to put a person in a position to speak with authority and decisiveness in their own field, and of-

[1]Collins and Evans (2002) recognized that their description of the previous waves is simplified almost to the point of caricature.

ten in other fields, too" (Collins & Evans, 2002, p. 239). The second wave is said to begin roughly in the 1970s, shortly after publication of Kuhn's *Structure of Scientific Revolutions*. The term *social constructivism* is often applied to this wave, which held that science is like other forms of social activity and therefore that scientific knowledge is the product of social interaction. (In her chapter, Nersessian documents how an anticognitive bias came in with constructivism.)

Collins and Evans (2002) proposed that the third wave in science and technology studies should focus on the study of experience and expertise (SEE). This move ought to bring sociological studies of science closer to cognitive approaches, because there is a cognitive literature on scientific expertise. Much of this literature is concerned with differences between experts and novices on the sorts of normal science problems encountered in textbooks. For example, in a classic study, Chi and her colleagues found that "that experts tended to categorize problems into types that are defined by the major physics principles that will be used in solution, whereas novices tend to categorize them into types as defined by the entities contained in the problem statement" (Chi, Feltovich, & Glaser, 1981, p. 150). Similarly, in another classic article, Larkin, McDermott, Simon, and Simon (1980) found that expert physicists working on familiar problems worked forward from the information given, and once a problem was appropriately categorized the rest of the problem-solving process consisted of relatively automatic procedures. Novice physics students, in contrast, had to struggle backward from the unknown solution, trying to find the right equations and quantities (Larkin et al., 1980).[2] For experts working in familiar domains, using pattern recognition skills to classify a problem is the first step toward solving it (Schunn & Anderson, 2001).

In these and other expert–novice studies (Clement, 1991; Green & Gilhooly, 1992), cognitive scientists were more concerned with how students get turned into normal scientists than with how scientific expertise was negotiated in a variety of settings. Nersessian in suggests in chapter 2 how expertise is negotiated in interdisciplines where disciplinary expertises are combined in novel ways. Negotiation need not be limited to social contexts, of course; Ippolito and Tweney (1995) discussed how Faraday "negotiated" a new expertise in a novel area of optics, and Gooding (e.g., 1990) has studied similar issues in other areas of Faraday's expertise.

[2]Consider an example: Suppose experts and novices have to find the friction coefficient for a block resting on an inclined plane. The weight of the block, the angle of the plane, and the force pushing against the block are given. Experts will work forward from the givens, generating the necessary equations, which in turn can be solved by familiar algorithms. The novice, in contrast, will typically start from the end point, trying to find values for the variables in the equation he or she must use at the end of the problem by generating other equations that use the givens (Anzai, 1991).

SEE has great potential for shedding light one the kinds of multidisciplinary interactions that are becoming prevalent on the cutting edge of technology, but only if combined with other concepts from the literature on science–technology studies. In this chapter I outline a framework that links SEE to other important concepts in the science and technology studies (STS) literature and apply this new SEE framework to two examples: (a) a converging-technologies initiative sponsored by the National Science Foundation and (b) an attempt to create a new kind of expert on human–environmental systems.

THREE TYPES OF EXPERTISE

Collins and Evans (2002) distinguished among three levels of shared expertise that can occur when more than one discipline is involved in scientific or technological problem solving.

1. None

Here two or more disciplines communicate only in the most superficial way, without any exchange of knowledge. An example would be a sociologist or anthropologist who studies a scientific laboratory without making any effort to understand the content, which was the approach taken by Latour and Woolgar (1986) in their classic study of laboratory life. A similar lack of understanding initially prevailed between AIDs activists who did not want to be in a placebo control group and scientists who insisted that was the only way to conduct appropriate trials of new medications (Epstein, 1996).

2. Interactional

Here the different disciplines have to be able to partially share domain-specific knowledge at a level of generality sufficient to complete a task. To continue our example, a sociologist or anthropologist studying a laboratory in this situation would learn enough about a scientific domain to permit thoughtful conversation with experts over matters of disciplinary content and method. Similarly, some AIDs activists educated themselves in scientific terminology to the point where they were able to interact with researchers. For example, Epstein (1995) described one activist who came into meetings with “seven earrings in one ear and a mohawk and my ratty old jacket on” and was dismissed initially as one of those street activists who had no expertise worth attending to. However, when she showed her growing command of the technical language, she won respect.

3. Contributing

Here practitioners from one discipline learn enough to make a real contribution to another. Pamplin and Collins (1975) conducted a sociological study of paranormal spoon bending and ended up coauthoring an article that made an important contribution to the psychokinesis literature, documenting instances of fraud and recommending improved research methods.

In the AIDs case, activists allied themselves with biostatisticians and others who succeeded in broadening the research protocols to include a more representative HIV positive population and to permit the use of other medicines taken in combination with the one on trial. The net effect of these modifications was to make the trials less rigorous from an experimental standpoint, but more ecologically valid from the standpoint of AIDs treatment. A small number of activists therefore contributed to AIDs research by becoming more like scientists—behavior that angered other AIDs activists.

Another example is the way in which Luis Alvarez combined his background in physics with his son Walter's expertise in geology to come up with a new hypothesis for the extinction of the dinosaurs and led a search for evidence (Alvarez, 1997).

These three types of expertise can be viewed as a continuum, shifting not only as an individual learns more about a domain of expertise but also as the nature of the problem shifts. Consider an example from one of the current projects at the University of Virginia. A group of us, supported by the National Science Foundation, are studying societal dimensions of nanotechnology.[3] Most of the funding goes to support a new nanotechnology student, who will serve as a participant–observer of her own learning process. In addition, she has been asked by her thesis advisors to look at the potential impact of her research on "world ills." Our goal is to make her a contributing expert in nanotechnology, at the level typical for Masters students. She might also gain contributing expertise in cognitive psychology of science, as she collaborates with Michael E. Gorman and Jeff Shrager on an analysis of her own cognitive processes.

In terms of ethical issues and global challenges, the initial goal is to make her an interactional expert, relying on the work of others to identify problems—but if her research involves a possible technological solution to any aspect of one of these problems, she will become a contributing expert. As one of her advisors, my goal right now is to become an interactional expert in nanotechnology and in her specific research area, but I want our team to

[3]The project is titled "Social and Ethical Dimensions of Nanotechnology" and is funded by NSF award SES-0210452.

make a significant contribution to an understanding of the societal dimensions of nanotechnology.

In contrast, Collins and Evans (2002) demarcated technical expertise from what they call the *public* or *political domain*—in which technical expertise carries no more weight than the expertise or views of any other stakeholder group. By extension, this argument implies that ethicists and policymakers do not need to interact with the expertise of a domain, just the implications of the research. The problem with this view is that one can only deal with social impacts after they are known, that is, when it is often too late. I think it is worth trying to see what happens if someone sensitized to societal dimensions is also capable of contributing to the creation of new technologies. This person would then blur the boundaries between the esoteric scientific domain and the public domain.

In both my case and the students', we begin with little expertise and move as quickly as possible to the interacting stage. The extent to which we get to the contributing stage will depend partly on the nature of the problems that emerge as we push into this new area.

TRADING ZONES

These three kinds of expertise can be linked to another important concept from the STS literature: trading zones:

> Two groups can agree on rules of exchange even if they ascribe utterly different significance to the objects being exchanged; they may even disagree on the meaning of the exchange process itself. Nonetheless, the trading partners can hammer out a *local* coordination, despite vast *global* differences. In an even more sophisticated way, cultures in interaction frequently establish contact languages, systems of discourse that can vary from the most function-specific jargons, through semispecific pidgins, to full-fledged creoles rich enough to support activities as complex as poetry and metalinguistic reflection. (Galison, 1997, p. 783)

Galison used the trading zone metaphor to describe the interactions among scientists and engineers developing radar and particle detectors.

Baird and Cohen (1999) applied the trading zone metaphor to an analysis of problems with the application of magnetic resonance imaging. Between 1987 and 1990,

> it became fashionable for physicians to reduce the rather long MR (magnetic resonance) imaging times by using anisotropically shaped (i.e., nonsquare) imaging pixels in studies of the spine. As it turned out, this resulted in a prominent dark line appearing within the spinal cord. The dark line was a Gibbs

> ringing artifact. Unfortunately, clinicians, not aware of this kind of artifact—for not being conversant with the mathematics used to transform the instrument signal into an image—at times interpreted this artifact as a disease process: a fluid filled lesion known as a "syrinx" requiring aggressive medical treatment. (Baird & Cohen, 1999, p. 238)

An individual who bridged medicine and physics detected the problem—too late for many patients. The creole among medicine, physics, and engineering was insufficient in this and other instances and needed constant updating.

THREE NETWORK STATES

Gorman and Mehalik (2002) proposed three states in networks that couple people with technology and link them with trading zones. The first state is a network controlled by an elite in which there really is no trade: Those not in the elite either obey, or they are ignored. The elite can be a group of experts who use their specialized knowledge to dictate how a sociotechnical system will function. The expertise of such an elite is black-boxed for other participants in the network. Communications are top-down, consisting primarily of directives that must be obeyed. Stalinist agricultural and manufacturing schemes used in the Soviet Union are examples of these elite control networks (Graham, 1993; Scott, 1998). State control overrode the experiential expertise of farmers, workers, and engineers. Similarly, AIDs activists felt that they were being forced to conform to a research protocol that did not honor their experiential knowledge of what it would take to recruit a representative sample of participants (Epstein, 1996).

The second is a more equal trading zone, in which experts from different fields interact around the development of a technological system, such as radar or magnetic resonance imaging. Such systems can serve as boundary objects, occupying a space at the focal point of several expertises, each of which has a somewhat different view of the emerging technology.

According to Bowker and Star (1999), boundary objects are "plastic enough to adapt to local needs and constraints of the several parties employing them, yet robust enough to maintain a common identity across sites" (p. 298). Boundary objects are "most useful in analyzing cooperative and relatively equal situations; issues of imperialist imposition of standards, force, and deception have a somewhat different structure" (p. 297). Therefore, boundary objects will be absent from trading zones that are dominated by an elite group but are likely to exist in trading zones where the partners are relatively equal.

In this kind of a trading zone, a system often serves as a boundary object that links the participants in the network (Hughes, 1998), where experts from different fields have different mental models of the system. One could adopt the term *boundary system* to refer to these cases (I consider the Everglades as an example later). A mental model, in this case, is a representation of the boundary system that is incomplete because each expert views the system in terms with which she or he is familiar. A good analogy is the "blind men and elephant problem," where the one feels the tail, another the trunk, another the leg, and each constructs a different beast consistent with his perspective.

The idea of a mental model would be anathema to sociologists of science, several of whom—as Nersessian noted in chapter 2—endorsed a moratorium on cognitive approaches to the study of science. A sociological reductionist might view the mind as epiphenomenal, as simply the by-product of social interactions—although even some sociologists reject this extreme position (Woolgar, 1987). In trading zones, however, people spend time trying to imagine each others' intentions, and they create and sustain different views of the evolving technological system, as Bijker (1995) showed in his excellent work on technological frames. Some parts of these imaginings are tacit—virtually impossible to articulate—and therefore cannot be completely captured in inscriptions or conversation. Tweney et al.'s efforts to replicate Faraday's experiments in chapter 7 are partly an effort to recover his tacit knowledge; see also Gooding's (1990) attempts to re-create a different set of experiments by Faraday. These tacit representations are frequent sources of misunderstandings in multidisciplinary trading zones (Gorman, 2002b). I use the term *mental model* to designate both individual and shared representations that are partly tacit and typically have visual and/or kinesthetic components.

For example, I have shown how Alexander Graham Bell based his telephone on a visual and kinesthetic analogy to the human ear that was unique to his experience and expertise (Gorman, 1997). In chapter 2, Nersessian suggests that mental models can include external devices as well as mental representations. Similarly, Carlson and I showed that these mental models could be partly embodied in devices, creating mechanical representations (Carlson & Gorman, 1990).

Human representations are themselves a boundary object between different disciplines, with sociologists studying people's inscriptions and conversations about reality and psychologists trying to study how people represent the world mentally and neurophysiologically. The term *mental model,* therefore, is not meant to be a step toward cognitive reductionism. Instead, I hope it will remind readers that as much as some sociologists, philosophers, behaviorists, and neuroscientists would like to wish it away, the age-old problem of how people represent their experience is still central to understanding human affairs.

AIDs activists and scientists from different disciplines learned to interact over a research protocol that served as a way of regulating a trading zone, in which those with AIDs would agree to certain guidelines for being enrolled in research and, in return, the guidelines were modified to make the protocol more inclusive. The creole that evolved involved AIDs activists learning scientific terms and scientists incorporating the arguments of activists in publications (Epstein, 1995).

Contributing expertise brings us to the third kind of trading zone, in which the participants share both a common understanding of a goal and a continually evolving representation (Tweney, 2001) of a technosocial system. In a State 2 trading zone, a technosocial system serves as a boundary object; in a State 3 network, the object or system moves from the boundary to the center of a growing, shared expertise. It is possible that a small number of AIDs activists and scientists achieved this kind of shared expertise for brief periods of time, but because Epstein (1995) did not use this framework, it is impossible to be certain. The free, collaborative exchange characteristic of the group that developed the Advanced Research Project Agency (ARPANET) is an example (Hughes, 1998).

Table 13.1 shows the relationship among the three levels of expertise, the three types of trading zone and three levels of intergroup communication. The three states, like the three types of expertise, are on a continuum. At State1 on one extreme, there is a top-down, "my way or the highway" network dominated by one group. Communications are in the form of instructions from the elite to the other participants, and the elite is solely concerned with evidence of obedience. State 2 covers the broadest range on the continuum, because it encompasses different kinds of negotiations among groups who begin with different areas of expertise, but where no one group is able to dominate the others. On the left, or State 1 end, would be networks in which different groups of experts try to "throw their parts of a technology over the wall" to each other. If a group cannot dominate the network, at least it can try to black-box its own part of a multidisciplinary project, demanding that other network participants just accept their contribution as given. Here the different groups resist developing a creole and try either to pull the boundary object under their control or shove it

TABLE 13.1
The Three Types of Trading Zone and Their Respective Levels of Expertise and Communication

	State 1	*State 2*	*State 3*
Trading zone	Elite control	Approximate parity	Shared mental model
Shared expertise	None	Interactional	Contributing
Communication	Orders	Creole	Shared meanings

into another group's responsibility. Farther to the right are State 2 networks that involve interactional expertise. Here participants have developed a creole that allows them to exchange important knowledge around a boundary object, partially opening each others' black boxes when necessary. A variety of hierarchical relationships may facilitate or hinder these State 2 networks, but if one group comes to dominate the hierarchy, the network shifts to a State 1.

Finally, on the State 3 end, there is a network that has to evolve a shared mental model to address what is typically a cutting-edge problem that stretches beyond anyone's disciplinary expertise. Here all participants are committed to a common goal and are often engaged in developing a new language to describe what they are doing. In this kind of a "skunkworks" environment, hierarchy is virtually ignored.

States in a network shift over time. AIDs research protocols initially served as a boundary object for activists, medical researchers, and statisticians, each of whom saw the protocols in a different way. Groups of activists initially demanded changes in the protocols, and researchers made some concessions—a primitive trading zone, more adversarial than cooperative. However, as activists grew in sophistication and attracted allies among statisticians, the trading zone became more collaborative, and the activists moved from reacting to interacting to, in some cases, contributing.

States also shift on the basis of how much of a system one includes in the network. Those inside the emerging ARPANET group operated mainly in a State 3, with experts from different disciplines working equally with managers to come up with novel solutions. ARPA's goal was to "find people that they thought were sufficiently smart and sufficiently motivated, give them a ball and let them run with it" (Hughes, 1998, p. 287). When asked how he knew what people and universities to fund, Joseph Licklider at ARPA said it depended on "a kind of networking. You learn to trust certain people, and they expand their acquaintance. And the best people are at the best universities, which one knows by reputation" (Hughes, 1998, p. 264). In other words, those not in a small, elite group of institutions could not get ARPA funding. For those on the outside, the ARPANET group constituted an elite into which they could not break; they were in an unequal trading zone with respect to what emerged.

I now apply this framework to two emerging areas of multidisciplinary collaboration.

CONVERGING TECHNOLOGIES FOR HUMAN PERFORMANCE

The NSF recently held a conference on "Converging Technologies (NBIC) for Human Performance," where the N stands for nanotechnology, the B for biotechnology, the I for information technology, and the C for cognitive science.[4] The model for collaboration that emerged was disciplinary depth combined with the ability to share expertise. The framework outlined previously allows us to discuss possible levels of sharing, on a continuum:

1. None, in which each discipline tries to dominate the trading zone or threatens to exit.
2. Interactional, in which disciplinary experts create creoles around boundary objects representing technological possibilities.
3. Contributing, in which experts from these four technologies engage each other deeply, learning enough to contribute jointly to development of a new technological system.

Consider, for example, how converging technologies could be used to create a “super soldier,” [5] featuring the following:

- Information technology to link the soldier into a command network that includes information on threats and support’
- Nanosensors to provide information about the immediate environment, including biological and chemical threats;
- Training on how to integrate all of this information into a cognitive system that can adapt rapidly;
- Genetic modifications that include improvements to the soldier’s physique and nervous system.

Each of these capabilities is coupled with the other ones, so at least a close interaction among expertises is required—and just as AIDs activists should have been involved in shaping research protocols involving themselves as participants, so too soldiers should be involved in these new technologies from the earliest design phases. Because this super soldier has the potential to become a Golem (Collins & Pinch, 1998) or even a Frankenstein,[6] another kind of expertise obviously needs to be added: ethics.

The question is whether this ethics expertise should belong to the political sphere that Collins and Evans (2002) set up as a separate trading zone. The risk is the same as that with the expert’s regress: Ethicists, politicians,

---

[4]For a pdf version of the report, see http://www.wtec.org/convergingtechnologies/ .

[5]See http://www.technologyreview.com/articles/talbot1002.asp for Massachusetts Institute of Technology’s ideas on how to use nanotechnology to create a super soldier.

[6]The Golem is a powerful, bumbling giant from Jewish mythology who does unintentional harm. Frankenstein’s monster, in contrast, took deliberate revenge on his creator. If the supersoldier technology becomes a Golem, it will have unintended side effects that will be harmful. If it becomes a Frankenstein, it might be turned against us by those entrusted with its use, or who obtain it.

and other stakeholders in a separate sphere will be reacting to the Golem after it has already been created, instead of being present at the moment a breakthrough occurs. An alternative would be to have practical ethicists join this super-soldier project as interacting experts, working closely with the researchers to explore societal implications as the technology produces new breakthroughs. Indeed, we might go a step farther and have ethicists and social scientists contributing to decisions about which set of experiments or potential designs a research team ought to conduct next—contributing in the sense that the ethicists are not philosopher-kings who dictate the research direction but simply members of the team, adding their expertise to the matrix of considerations.

Here I use *expertise* in the broadest sense, to include wisdom (Gorman, 2002a). An example of such wisdom is the ability to engage in moral imagination, which involves going "out toward people to inhabit their worlds, not just by rational calculations, but also in imagination, feeling, and expression" (Johnson, 1993, p. 200). Ethicists and social scientists need to help scientists and engineers imagine the potential impact of new technologies on a wide variety of stakeholders, especially at the point where new research directions are under serious consideration.

EARTH SYSTEMS ENGINEERING MANAGEMENT

Brad Allenby, a prominent industrial ecologist, has called for this kind of contribution from social scientists and ethicists in the development of Earth Systems Engineering Management (ESEM), a new approach to human–environmental systems (Allenby, 2001). ESEM is discussed in more detail in chapter 14, by Allenby. For now, it will suffice to say that ESEM begins with the premise that no corner of the globe is unaffected by human beings, given our technological "advances," and therefore we have a responsibility to manage our planet intelligently. Human beings, nature, and technology are all closely coupled in a dynamic system whose interactions are hard to predict.

Therefore, ESEM is what Collins and Evans (2002) referred to as a *reflexive historical science,* or one in which "the long-term outcomes are affected by humans themselves." [7] The global environment is a complex dynamic system that is affected by human activities, including our attempts to understand and manage it; therefore, it is a reflexive historical science. This kind of system requires continuous monitoring and technologies whose impacts

[7] Collins and Evans's (2002) other types of science include *normal science,* in which consensus in the community of experts has been achieved; *Golem science,* in which an eventual consensus is likely, but none exists at present; and *historical sciences,* in which consensus will take a long time because the system itself is complex and needs to be studied over an extended duration.

can be reversed if the monitoring indicates an unexpected change in the system state. Most environmental regulation involves a trading zone among multiple agencies with interacting expertise (Jasanoff, 1992), but ESEM implies moving beyond this kind of careful, often-adversarial trading zone to a continuous dialogue with the complex system that will produce shared representations—a dialogue that will include knowledge scientists and ethicists as contributing experts.

Consider the Everglades, home to 68 endangered species, multiple ecosystems, and a rapidly growing urban landscape that depends on the "river of grass" for water.[8] Management of this system is currently a complex trading zone among multiple stakeholders, linked by a multibillion dollar restoration plan that incorporates different mental models. The U.S. Park Service wants to restore the Everglades to its natural state, including the preservation of indigenous species and elimination of invasives.

The South Florida Water Management District (SFWMD) sees the park and surrounding lands as a huge reservoir. Their mission is to provide water to a growing urban area and control flooding, although they are committed to working on restoration where it does not interfere with those goals. The Army Corps of Engineers has a restoration mandate from Congress but also flood control and drinking-supply mandates from its history and from its work with the SFWMD. The corps is locked by legislation into a 50:50 trading zone with the SFWMD.

For agricultural interests, particularly sugar, the Everglades is a giant waste treatment facility. Sugar plantations are built right on the compost left over from centuries of sawgrass and other organics. The sugar industry claims that the Everglades could tolerate phosphorus levels of up to 20 parts per billion, whereas the SFWMD and the Florida Department of Environmental Protection established the level at 10 parts per billion. The SFWMD has designed artificial wetlands near the sugar plantations to treat phosphorus and other agricultural runoff, but current models cannot ensure that this strategy will sufficiently mitigate downstream impacts (Sklar, Fitz, Wu, Zee, & McVoy, 2001).

These examples only begin to suggest the complexity of the trading zone that continues to evolve around the Everglades as a boundary system. To appreciate the tensions, consider a boundary object within this system: the Tamiami canal, which keeps water from the north from entering the Everglades Park, except through a system of small dams controlled by the Army corps and the SFWMD. If the natural flow of the Everglades is to be restored, the entire levy and dam system will have to be removed and the

[8]Much of the material in this Everglades section is based on interviews and observations I and one of my students (Charles Jansen) conducted on a field trip, supported by ESEM funding from AT&T.

existing road replaced by an overpass. Once the overpass is built and the levy is gone, it is hard to dam the water again—and the flow effects may not be restorative, given how other parts of the system are managed. For example, if phosphorus levels continue to increase in the northern part of the system, then greater flow will spread the pollution more rapidly and widely. More of the natural floods would occur, with catastrophic consequences for development. If greenhouse warming continues, then the salt water could move up from the southern part of the system without any dams to check it.

This example illustrates how a boundary object can be embedded in a boundary system and how the possibilities for the object are linked to the mental model of the system. If one's goal is to restore the Everglades to an earlier system state, then one sees the canal as an obstruction. If one sees the Everglades as a reservoir, one sees the canal as an essential component in flood control.

The current trading zone is managed by volumes of regulations, codes, and plans (SFWMD, 2002). All of these agreements are valuable, but if participants in the trading zone still see each other as having competing goals, then no documents will suffice for genuine cooperation across a system as complex as this.

The Everglades is an example of the kind of system an earth systems engineer (ESE) should be able to help us manage. An ESEM expert would have to create at least occasional State 3 moments in this State 2 network, to engage a core of participants in the kind of dialogue that might shift the Everglades from a boundary object to a shared mental model. What kind of a "natural" system are we trying to restore? The Everglades would continue to be a changing system, anyway, but human technology has greatly accelerated the changes and taken them in new and unexpected directions. Now we have to choose system toward which goals to work, collect information, and create models that allow us to adjust quickly to unanticipated perturbations. These goals need to be synergistic: One cannot have unlimited development, unlimited access to water, no flooding, and restoration of the Everglades as it existed centuries ago.

The Everglades are, of course, part of the larger global environmental system and cannot be managed in isolation. For example, the ESE will have to consider the impact of global climate change.

New technologies and scientific methods would emerge from this kind of collaboration, as in the case of other multidisciplinary collaborations, such as converging technologies. How, for example, could a system be created to allow extended flow across the Tamiami in a way that could be reversed quickly if unanticipated negative consequences occurred? Perhaps new materials made available by advances in nanotechnology might help, along with intelligent agents that can give feedback on minute changes in the flow and respond after alerting the ESE.

DISCUSSION

To understand and improve multidisciplinary collaboration, cognitive and social approaches to STS have to be integrated. The framework outlined in this chapter integrates SEE, trading zones, boundary objects, and cognitive representations. The three network states proposed in this chapter make us aware of significant shifts in relationships among practitioners—especially experts—that are both social and cognitive. For example, a boundary system is represented in unique ways by different disciplinary participants in a State 2 trading zone; in a State 3 network, all participants need to share a mental model of the system they are creating.

This framework will, of course, be modified and elaborated by future research and perhaps even abandoned—although old frameworks rarely die, they just get absorbed into new ones. In particular, this framework makes the prediction that State 3 networks are essential to breakthroughs in multidisciplinary science and technology, especially breakthroughs that truly benefit society. This prediction should be explored in both current and historical case studies.

ACKNOWLEDGMENTS

Portions of this chapter were drawn from my 2002 article, "Levels of Expertise and Trading Zones: A Framework for Multidisciplinary Collaboration," *Social Studies of Science, 32*(5–6), although the argument here is greatly expanded and revised. I thank Ryan Tweney, Brad Allenby, and Jeff Shrager for their comments.

REFERENCES

Allenby, B. (2001). Earth systems engineering and management. *IEEE Technology and Society Magazine, 19*(4), 10–21.

Alvarez, W. (1997). *T.rex and the crater of doom*. Princeton, NJ: Princeton University Press.

Anzai, Y. (1991). Learning and use of representations for physics expertise. In K. A. Ericsson & J. Smith (Eds.), *Toward a general theory of expertise* (pp. 64–92). Cambridge, England: Cambridge University Press.

Baird, D., & Cohen, M. (1999). Why trade? *Perspectives on Science, 7,* 231–254.

Bijker, W. E. (1995). *Of bicycles, bakelites and bulbs: Toward a theory of sociotechnical change*. Cambridge, MA: MIT Press.

Bowker, G. C., & Star, S. L. (1999). *Sorting things out: Classification and its consequences*. Cambridge, MA: MIT Press.

Carlson, W. B., & Gorman, M. E. (1990). Understanding invention as a cognitive process: The case of Thomas Edison and early motion pictures, 1888–1891. *Social Studies of Science, 20*, 387–430.

Chi, M. T. H., Feltovich, P. J., & Glaser, R. (1981). Categorization and representation of physics problems by experts and novices. *Cognitive Science, 5,* 121–152.

Clement, J. (1991). Nonformal reasoning in experts and science students: The use of analogies, extreme cases, and physical intuition. In J. F. Voss, D. N. Perkins, & S. J. W. (Eds.), *Informal reasoning and education* (pp. 345–362). Hillsdale, NJ: Lawrence Erlbaum Associates.

Collins, H. M., & Evans, R. (2002). The third wave of science studies. *Social Studies of Science, 32,* 235–296.

Collins, H., & Pinch, T. (1998). *The Golem at large: What you should know about technology*. Cambridge, England: Cambridge University Press.

Epstein, S. (1995). The construction of lay expertise: AIDs activism and the forging of credibility in the reform of clinical trials. *Science, Technology & Human Values, 20,* 408–437.

Epstein, S. (1996). *Impure science: AIDs, activism, and the politics of knowledge*. Berkeley: University of California Press.

Galison, P. (1997). *Image & logic: A material culture of microphysics*. Chicago: University of Chicago Press.

Gooding, D. (1990). *Experiment and the making of meaning: Human agency in scientific observation and experiment*. Dordrecht, The Netherlands: Kluwer Academic.

Gorman, M. E. (1997). Mind in the world: Cognition and practice in the invention of the telephone. *Social Studies of Science, 27,* 583–624.

Gorman, M. E. (2002a). Turning students into professionals: Types of knowledge and ABET engineering criteria. *Journal of Engineering Education, 91,* 339–344.

Gorman, M. E. (2002b). Types of knowledge and their roles in technology transfer. *Journal of Technology Transfer, 27,* 219–231.

Gorman, M. E., & Mehalik, M. M. (2002). Turning good into gold: A comparative study of two environmental invention Networks. *Science, Technology & Human Values, 27,* 499–529.

Graham, L. R. (1993). *The ghost of the executed engineer: Technology and the fall of the Soviet Union*. Cambridge, MA: Harvard University Press.

Green, A. J. K., & Gilhooly, K. J. (1992). Empirical advances in expertise research. In M. T. Keane & K. J. Gilhooly (Eds.), *Advances in the psychology of thinking* (Vol. I, pp. 45–70). London: Harvester Wheatsheaf.

Hughes, T. P. (1998). *Rescuing Prometheus*. New York: Pantheon.

Ippolito, M. F., & Tweney, R. D. (1995). The inception of insight. In R. J. Sternberg & J. E. Davidson (Eds.), *The nature of insight* (pp. 433–462). Cambridge, MA: MIT Press.

Jasanoff, S. (1992). Science, politics and the renegotiation of expertise at EPA. *Osiris, 7,* 195–217.

Johnson, M. (1993). *Moral imagination*. Chicago: University of Chicago Press.

Kuhn, T. S. (1962). *The structure of scientific revolutions*. Chicago: University of Chicago Press.

Larkin, J. H., McDermott, J., Simon, D. P., & Simon, H. A. (1980, June 20). Expert and novice performance in solving physics problems. *Science, 208,* 1335–1342.

Latour, B., & Woolgar, S. (1986). *Laboratory life: The construction of scientific facts*. Princeton, NJ: Princeton University Press.

Pamplin, B. R., & Collins, H. (1975). Spoon bending: An experimental approach. *Nature, 257,* 8.

Schunn, C. D., & Anderson, J. R. (2001). Acquiring expertise in science: Explorations of what, when and how. In K. Crowley, C. D. Schunn, & T. Okada (Eds.), *Designing* *for science: Implications for everyday, classroom, and professional settings* (pp. 83–114). Mahwah, NJ: Lawrence Erlbaum Associates.

Scott, J. C. (1998). *Seeing like a state: How certain schemes to improve the human condition have failed*. New Haven, CT: Yale University Press.

Sklar, F. H., Fitz, H. C., Wu, Y., Zee, R. V., & McVoy, C. (2001). The design of ecological landscape models for Everglades restoration. *Ecological Economics, 37,* 379–401.

South Florida Water Management District. (2002). *2002 Everglades Consolidated Report*. West Palm Beach, FL: Author.

Tweney, R. D. (2001). Scientific thinking: A cognitive–historical approach. In K. Crowley, C. D. Schunn, & T. Okada (Eds.), *Designing for science: Implications for everyday, classroom, and professional settings* (pp. 141–173). Mahwah, NJ: Lawrence Erlbaum Associates.

Woolgar, S. (1987). Reconstructing man and machine: A note on sociological critiques of cognitivism. In W. E. Bjiker, T. Hughes, & T. Pinch (Eds.), *The social construction of technological systems* (pp. 311–328). Cambridge, MA: MIT Press.