4 Balancing Practice-Centered Research and Design

DAVID WOODS
The Ohio State University

KLAUS CHRISTOFFERSEN
The Ohio State University

ABSTRACT

Many are interested in Research and Development (R&D) at the intersection of people, technology and work. R&D is a world divided and hobbled. Innovation is tantalizing yet elusive. In a rush, we achieve only a cumbersome process of trial and error (publicizing the extent of design errors and failures would be bad for investment). The standard metaphor and organizational construct of the pipeline has failed given the possibilities for change and the predilection for new technology to demand connections across disciplinary boundaries. R&D in this area is a world too often without effective interconnections and cross-stimulation. This piece provides an alternative model at two levels. First, it presents complementarity as a strategy for practice-centered research and design. The strategy is foundational for the intent behind the label *cognitive systems engineering* (and related labels like *distributed cognition, naturalistic decision making*, and on and on) as an alternative to traditional disciplinary approaches. Second, it replaces the shopworn cliché of an R&D pipeline (a metaphor that may never have had substance) with synchronization of multiple parallel cycles of learning and development that operate at different time scales. Interlocking these cycles is a difficult challenge—a challenge in producing an organizational framework and supporting mechanisms to create and extend distributed innovation.

4.1 BROKEN PIPES

Many are interested in Research and Development (R&D) at the intersection of people, technology, and work. Developers and technologists make claims about how a prospective new capability or new system development project will impact on performance in one or many settings. Sponsors are caught up in the sweeping dreams permitted by technology unfettered from harsh contexts of use, yet they fear software development projects that fail to provide useful tools or that create unanticipated negative effects. Practitioners and observers of practitioners at work note repeated forms of clumsiness in the technology deployed and unanticipated side effects of change. Researchers, blinded by the glare of disciplinary labels, drastically reduce situations to fit into a lab one variable at a time yet claim priority in the search for generic regularities. Human factors practitioners and usability engineers are called in too late to repair the connection between systems and use. Research results seem irrelevant to design. Design seems local and unique.

R&D at the intersection of people, technology, and work is a world divided and hobbled. Innovation is tantalizing yet elusive. In the rush, we achieve only a cumbersome process of trial and error (publicizing the extent of design errors and failures would be bad for investment). The standard metaphor and organizational construct of the pipeline has failed given the possibilities for change and the predilection for new technology to demand connections across disciplinary boundaries. R&D in this area is a world too often without effective interconnections and cross-stimulation.

We provide an alternative model at two levels. The first attribute is *complementarity* as a strategy for practice-centered research and design. This is the foundational strategy behind the label *cognitive systems engineering* (and related labels like *distributed cognition* and *naturalistic decision making*) that makes it a substantive alternative to traditional disciplinary approaches. In other words, all the new labels about the syntheses required to study and shape the intersection of people, technology, and work are only superficial exercises in career enhancement unless they provide substance to complementarity.

Second, the model here replaces the shopworn cliché of an R&D pipeline (a metaphor that may never have had substance) with synchronization of multiple, parallel cycles of learning and development that operate at different time scales. Interlocking these cycles is a difficult challenge—a challenge in producing organizational framework and supporting mechanisms to create and extend *distributed innovation*.

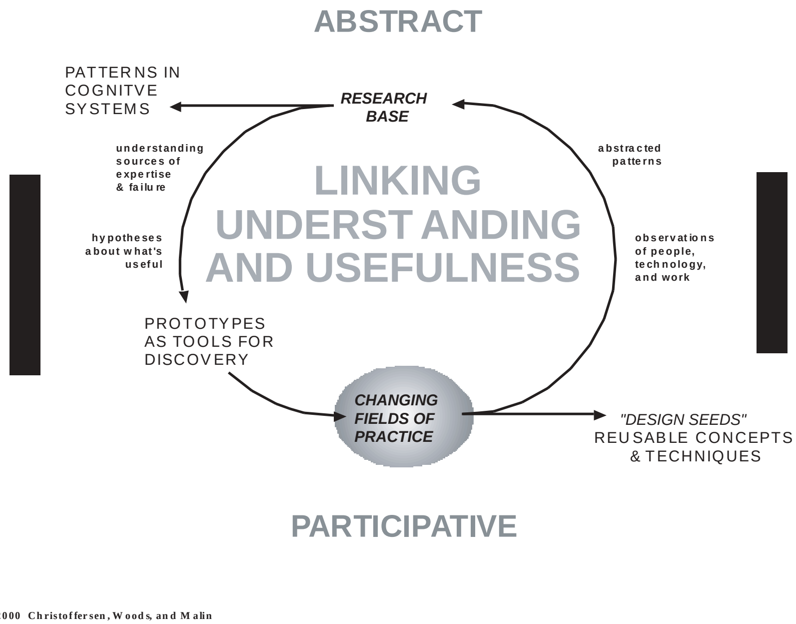

Figure 4.1: A practice-centered approach to research. Complementarity defines cognitive systems engineering in the innovation process.

4.2 COMPLEMENTARITY AS A STRATEGY TO BALANCE RESEARCH AND DESIGN

Two coordinated strands define complementarity (see Figure 4.1). In one strand (see Figure 4.2), inquiry is directed at capturing phenomena, abstracting patterns, and discovering the forces that produce those phenomena despite the surface variability of different technology and different settings. In this sense effective research develops a book of "patterns" as a generic but relevant research base.

But the challenge of stimulating innovation goes further. A second strand of processes are needed that link this tentative understanding to the process of discovering what would be useful (see Figure 4.3). Success occurs when "reusable" (that is, tangible but relevant to multiple settings) design concepts and techniques are created to "seed" the systems development cycle.

Discovery of what would be useful occurs in the research cycle because

- Development also functions as opportunities to learn. Artifacts are not just objects; they are hypotheses about the interplay of people, technology, and work. In this cycle prototypes function as tools for discov-

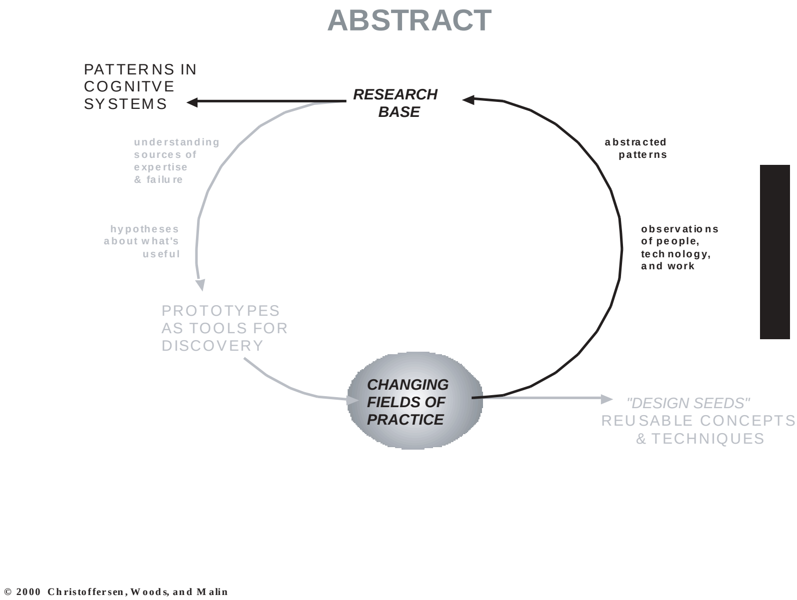

Figure 4.2: Discovering patterns in cognition at work. Observing, abstracting, explaining phenomena at the intersection of people, technology, and work.

ery to probe the interaction of people, technology, and work and to test the hypothesized, envisioned impact of technological change.

- •. The limited resource horizon of all development projects always places limits on learning and exploring. Inevitably in development projects, prototypes function only as partially refined final products, and the design mindset narrows in on critical paths toward and impasses that could block the realization of a tangible object in a particular setting. Seeding future development cycles with new reusable concepts about what would be useful requires a longer-term focus.

In the end, innovation is stimulated through both creation of possible futures and reflection about the effects of those changes while the commitment to any particular object is relaxed and the limited horizon of development cycles is stretched. The combination creates a complementary cycle of learning and development (see Figure 4.1). Advancing our understanding abstracts patterns and phenomena from observations of the interplay of people, technology, and work and develops explanations for the appearance of these patterns across different fields of practice. This cycle seeks to discover performance-related issues within each given setting and to develop hypotheses about what may be useful

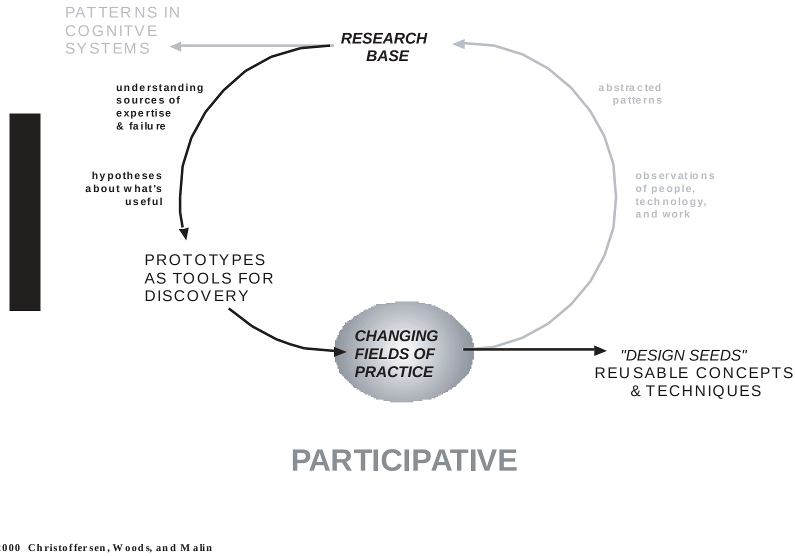

Figure 4.3: Leveraging research to generate useful design concepts. Generating reusable concepts about what would be useful to seed development.

in response to these issues. Aiding concepts are embodied in prototypes as part of a continuing learning and discovery process. Over time, the result is a generically defined set of concepts and techniques that can seed development in multiple specialized areas where the relevant performance issues play out.

An effective balance generates two types of advances, each as tentative syntheses of what we think we know about the interplay of people, technology, and work (Figure 4.1, A practice-centered approach to research). The research base is seen as patterns abstracted across different unique settings, patterns that are in need of explanation and concepts that could explain these observations. As Hutchins (1999) put it, “There are powerful regularities to be described at a level of analysis that transcends the details of the specific domain. It is not possible to discover these regularities without understanding the details of the domain, but the regularities are not about the domain specific details, they are about the nature of human cognition in human activity.”

The second product of an effective balance would be the ability to capture and share design “seeds”—concepts and techniques about what would be useful to advance cognition and collaboration at work. These are seeds in the sense that they represent concepts that are sensitive to constraints that arise in multiple settings and they can stimulate development across different specific settings. “If we are to enhance the performance of operational systems, we need conceptual looking glasses that enable us to see past the unending variety of technology and particular domains" (Woods & Sarter, 1993). To achieve this complementarity, usefulness (i.e., criteria that new systems enhance performance in context) becomes a criteria for research. How does the concept effectively seed and leverage development in more than a specific case?

In coordinating these processes, four values guide R&D activities. Fields of practice are the primary focus. *Authentic* samples of what it means to practice in that field of activity and how the organizational dynamics pressure or support practice stimulate the process of observation. However, observers will quickly become lost in the detail of particular settings at particular points in time with particular technological objects unless they can compare and contrast settings over time to *abstract* patterns and produce candidate explanations for the basic patterns. The third component is generative—in studying the interaction of people, technology, and work across fields of practice we must *generate* or discover new ideas, including explanations for the phenomena and patterns observed, but more critically, new hypotheses about what would be useful to probe the field of practice, test our tentative understanding, and to seed upcoming development cycles. In the final analysis the activity is *participative* as we work with practitioners in these fields of activities to understand how they adapt to the pressures and demands of the field of activity.

The two half cycles (Figures 4.2 and 4.3) are interdependent, not separate. The point of the processes of observation, abstraction, and explanation is to find the essential factors under the surface variability. In other words, the test of understanding is the ability to anticipate the impacts of technological change. The ultimate risk for the researchers is to acknowledge that they are part of the process under study. The researcher participates in the struggle of envisioning with other stakeholders. Researchers also must acknowledge their role as designers—the development of tools that make us smart or dumb. The ultimate test for the designers is to risk abstraction and acknowledge their prototypes as hypotheses at empirical jeopardy.

Thus, in a practice-centered process we face challenges related to the four basic values:

- Transcending *limits to authenticity* to capture how the strategies and behavior of people are adapted to the constraints and demands of fields of practice.
- Meeting the *challenge of abstraction* to find and explain patterns behind the surface variability.
- *Sparking inventiveness* to discover new ways to use technological possibilities to enhance human performance, to identify leverage points, and to minimize unanticipated side effects.
- *Creating future possibilities* as participants with other stakeholders and problem holders in that field of practice.

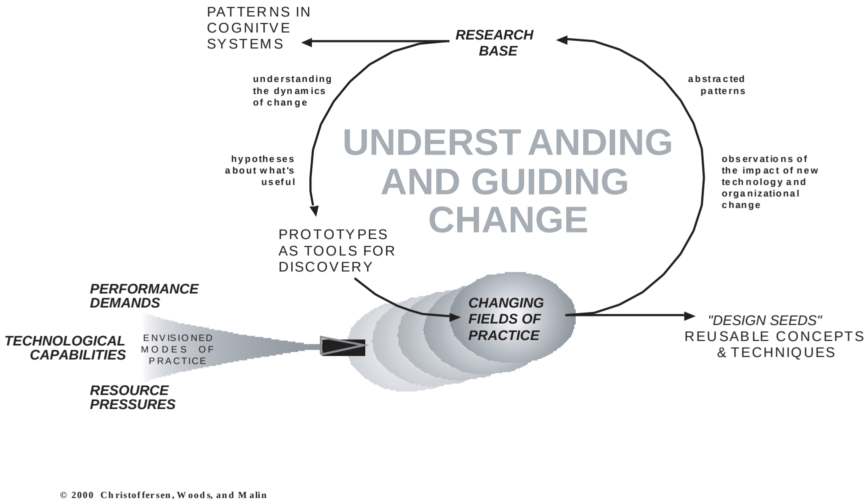

Figure 4.4: The envisioned world problem: A moving target for design.

These are generic, but relevant; finding in the particular the existence and expression of universal patterns—these are not contradictions or conflicts but creative tensions at the root of complementarity, harnessed for innovation.

4.3 MOVING TARGET

Achieving the complementarity captured in Figure 4.1 is in fact quite difficult for a number of reasons. One is captured in Figures 4.4 and 4.5, which creates a moving target for development. Fields of practice are not static; rather demands, pressures, and resources are changing. New possibilities are envisioned and advocates push their particular vision, but the introduction of new systems transforms the nature of practice through new roles, new judgments, new forms of coordination, and new paths toward and forms of breakdown.

We usually see new computerization as a solution to performance problems or limits. In others words, advancing the baseline of technology and focused development projects in specific areas require envisioning future operations. However, envisioned operation concepts have two basic properties:

- *Plurality*—there are multiple versions of how the proposed changes will affect the character of the field of practice in the future; and

- *Underspecification*—each envisioned concept is vague on many aspects of what it would mean to function in that field of practice in the future.

New technology is a source of change as performance demands and resource pressures change. New technology becomes wrapped up in organizational change as well. The question then is—can design anticipate the full range of effects of the change? Usually, technology change produces unintended and sometimes negative side-effects in addition to new capabilities. Thus, we are part of a dynamic process that we also wish to understand and influence—a dynamic process of technology change generating a new set of capabilities and complexities, leading to adaptations by stakeholders, producing a changing mix of success and failure.

In addition to plurality and underspecification, envisioned modes of operation are a *prediction* about the effects of change on people, technology, and work. As predictions, envisioned concepts can have two other properties:

- *Ungrounded*—envisioned concepts can easily be disconnected or even contradicted from the research base on the actual consequences of the changes on people, technology and work.
- *Overconfident*—advocates are miscalibrated and overconfident that, if the systems envisioned can be realized, the predicted consequences and only the predicted consequences will occur.

The envisioned world problem demands that we develop means to ground predictions on relevant empirical results abstracted from observations in context. Understanding the dynamic process of change and adaptation will lead to better control of the process—essentially an innovation process at the intersection of people, technology, and work. Armed with knowledge about the dynamics of change and adaptation, we can address potential side effects at a time when intervention is less difficult and less expensive (because the field of practice is already in a period of change and systems development is in the process of creating tangible objects).

4.4 SYNCHRONIZING PARALLEL, INTERLOCKING CYCLES

Figure 4.5 also broadens the context for practice-centered research and design to indicate the relationship to the systems development process.

In the added development cycle, teams develop systems to address problems that arise in a specialized field of practice (for example, topics of recent interest for the Air Force are distributed replanning and unmanned aerial vehicles). In this cycle, a resource horizon drives the scope of development, and there are constraints at multiple levels of realization which need to be balanced

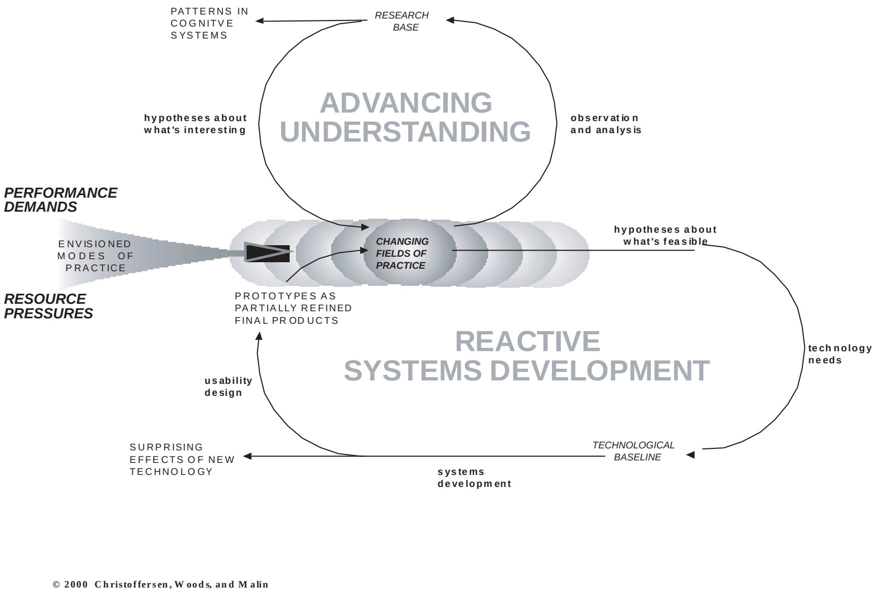

Figure 4.5: Mis-synchronized cycles.

in a successful product. As a result, (1) there is a process of matching requirements to technological possibilities, (2) prototypes function as partially refined final products, (3) usability testing refines the potential product to fit the field of practice, and (4) the end result is tangible systems that can be introduced into a specific field of practice.

Figure 4.6 adds the third cycle of learning and development to complete the picture. In the bottom cycle, research technologists advance the technological baseline either by expanding the capabilities of autonomous technology or by increasing the availability of technological capabilities (reducing cost, expanding access to technological capabilities).

The graphic illustrates the kind of balance and cross-stimulation across these traditional R&D activities that can enhance innovation in the search for useful systems. This coupling creates an organization that is sensitive and responsive to the needs and opportunities for improving performance in complex socio-technical systems.

The challenge is interlocking and *synchronizing* these multiple cycles. When these cycles are balanced, complementary processes, they drive the innovation process by which technological possibilities are harnessed to advance performance and reduce risks of development in specific fields of practice. Achieving

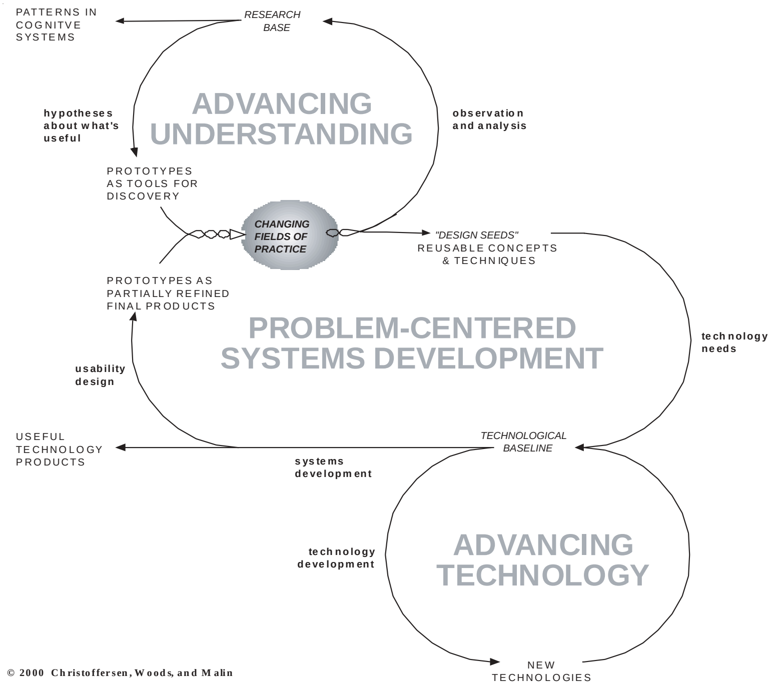

Figure 4.6: The engine of innovation: Balanced cycles. Synchronization of cycles as an alternate to the pipeline model of R&D.

balance requires *effort-after-coordination* as people working in each area step outside of their own activities to see the relationship to the other cycles.

4.5 IMBALANCE

But each of the cycles happens at different time scales, which makes synchronization difficult. Each of these cycles has its own criteria for success, which pushes personnel deeper into their own role and subgoals. Without organizational support and investment, the cycles spin apart, out of balance, and fail to mutually reinforce each other. The result is journal papers that provide no insight as to the real phenomena, lack of innovative uses of new possibilities, new technology that users see as clumsy in context, and the same problems ("classics") and questions re-appear with limited or no progress (Figure 4.7).

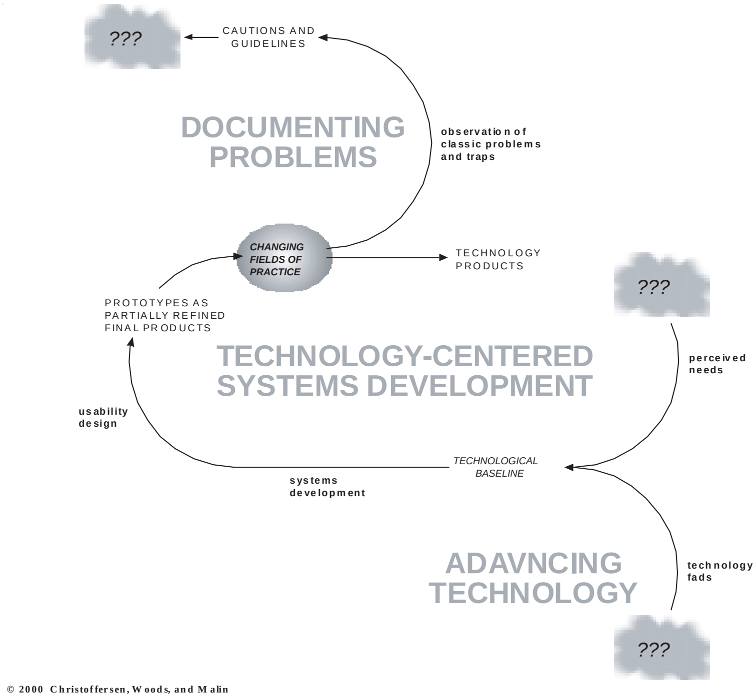

Figure 4.7: The engine of frustration: A recipe for design by trial and error. How the balance breaks down.

4.6 POINTS OF BALANCE

The key to balancing these cycles lies in their connections with one another. As interlocking cycles, each one stimulates and guides the others in a process centered around the dynamic processes evident in changing fields of practice. Coupling the uppermost and middle cycles ensures that research is relevant and representative, while providing a base of analytical perspectives and design concepts that is portable across domains and that can be leveraged in systems development. Research is integral and important when it can proactively suggest promising design directions, rather than simply critiquing poor designs retrospectively, when opportunities for modification are limited. The introduction of a prototype into a given setting functions as a way to test and refine it as a product (the middle cycle), but also represents a natural experiment (the top cycle but at a different time constant) on the behavior of the socio-technical system and the effectiveness of the aiding concepts embodied by the prototype (artifacts are hypotheses about the interplay of people, technology, and work). Recognizing and maintaining these separate but parallel statuses of prototypes maximize the organization's informational return on investment during development. When these cycles aren't closely coupled, the result is a design process that progresses primarily by trial and error, and a human factors organization that is perennially behind the curve.

When in balance, there are means to relate artifacts (i.e., what is technologically possible) to cognitive systems (i.e., what would be useful) and to the limited resource horizons of real development. If the technology development process is disconnected from systems development, and from the research base on "artifacts, their uses and effects," the result can be a very low "hit rate" of useful new systems. Rather than just measure success in terms of autonomous machine capabilities, technology developers must look empirically at what will support effective performance within the larger socio-technical system.

The challenge is interlocking and synchronizing these multiple cycles. When these multiple cycles are balanced, complementary processes, they drive the innovation process by which technological possibilities are harnessed to advance performance and reduce risks of development in specific fields of practice.

4.7 DIFFERENT ROLES FOR HUMAN-FACTORS-RELATED WORK

Work related to themes on human factors can go on in each of the three cycles. Research that advances technology can be about technology for interacting with people, for example, advancing the capability of augmented reality or natural language technology. Research that advances our understanding of the interaction of people, technology, and work should generate concepts and techniques that could be used in different development projects; for example, patterns in data overload or supervisory control of automation lead to design concepts and techniques to make automated systems team players. Usability engineering plays a role in systems development, early by using seed concepts from the research base to identify leverage points, and later through usability design and testing.

4.8 COMPLEMENTARITY AND SYNCHRONIZATION

The graphics in this series do not distinguish research and application. Research does not flow down to application. Instead, we need to situate activities of practice-centered research and design in the larger process of systems development for specialized target areas and relative to the general expansion in technological possibilities.

Researchers are connected to the systems development process by observing and abstracting patterns about the interaction of people, technology, and work. These researchers must be able to contribute concepts and techniques about what would be useful in the initial stages of a development cycle, but they are relaxed from the limited resource and time horizons that pressure development of real working systems.

Those working to advance technology for human interaction are connected to the systems development process by using or participating in studies of the actual effects of technology change. Rather than just measure success in terms of autonomous machine capabilities, they can look to the research base for empirically based patterns and models about how technology developments support effective collaboration with human practitioners.

Effective innovation in system development depends on having technological advances to draw on and on having concepts about what may be useful to support human performance available early in a development cycle to be able to identify leverage points and to anticipate side effects of change.

In effect, the balancing act needs mechanisms to support *distributed innovation.* This is an example of the area of human-machine systems called computer-supported collaborative work or CSCW. Usually this work is directed at practitioners, designers, or managers. Here the need is to use principles for collaborative work and the technology infrastructure for connectivity to support distributed innovation. Doing this, as building any kind of collaboration, requires energy and investment in coordinated activities across the multiple parallel cycles.

4.9 ACKNOWLEDGMENTS AND RECOMMENDED READING

The perspective developed here is derived from and continues a series of papers on design and productions on the role of cognitive systems engineering in research and design. In particular, it is based on and drawn from a plenary address at the 44th Annual Meeting of the Human Factors and Ergonomics Society and International Ergonomic Association, August 2, 2000 and the accompanying material in *Ergonomics* (D. Woods, K. Christoffersen, and D. Tinapple, Complementarity and Synchronization as Strategies for Practice-Centered Research and Design). Much of this chapter is taken directly from this production and paper.

The ideas were developed, first, as part of research projects on Cooperative Cognition sponsored by NASA and second as part of research projects on Data Overload sponsored by the Air Force Research Laboratory, Wright-Patterson Air Force Base (WPAFB). Jane Malin of NASA and Gil Kuperman of WPAFB were instrumental in stimulating, critiquing, and nurturing the development of these ideas in these projects.

The series of papers and multimedia productions on design that lead up to and buttress the framework of complementarity and synchronization include:

- Woods, D.D. (1998). Designs are Hypotheses about How Artifacts Shape Cognition and Collaboration. *Ergonomics, 41*, 168–173.

- Woods, D.D., Patterson, E.S., Corban J., & Watts, J.C. (1996). Bridging the Gap between User-Centered Intentions and Actual Design Practice. *Proceedings of the 40th Annual Meeting of the Human Factors and Ergonomics Society*. Santa Monica, CA: Human Factors & Ergonomics Society.
- Woods, D.D., & Tinapple, D.W (1999), *Watching Human Factors Watch People at Work*. Presidential Address, 43rd Annual Meeting of the Human Factors and Ergonomics Society. Houston, TX. [Multimedia production at http://csel.eng.ohio-state.edu/hf99/]
- Potter, S.S., Roth, E.M., Woods, D.D., & Elm, W. (2000). Bootstrapping Multiple Converging Cognitive Task Analysis Techniques for System Design. In J.M.C. Schraagen, S.F. Chipman, & V.L. Shalin (Eds.), *Cognitive task analysis*. Mahwah, NJ: Erlbaum.
- Dekker, S., & Woods, D.D. (1999). Extracting Data from the Future: Assessment and Certification of Envisioned Systems. In S. Dekker & E. Hollnagel (Eds.), *Coping with computers in the cockpit* (pp. 7–27). Aldershot, UK: Ashgate.
- Hoffman, R., & Woods, D.D. (2000). Studying Cognitive Systems in Context. *Human Factors, 42*(1), 1–7.

REFERENCES

- Hutchins, E. (personnel communication, 1992).
- Woods, D.D. & Sarter, N.B. (1993) Evaluating the impact of new technology on human-machine cooperation. In J. . Stager (Eds.), *Verification and validation of complex and integrated human machine systems.* Berlin: Springer-Verlag.