Human-Computer Interaction: Psychological Aspects of the Human Use of Computing

Article *in* Annual Review of Psychology · February 2003

DOI: 10.1146/annurev.psych.54.101601.145044 · Source: PubMed

2 authors:


Gary M. Olson
University of California, Irvine


Judith S. Olson
University of California, Irvine

Annu. Rev. Psychol. 2003. 54:491–516
doi: 10.1146/annurev.psych.54.101601.145044

First published online as a Review in Advance on August 27, 2002

HUMAN-COMPUTER INTERACTION: Psychological Aspects of the Human Use of Computing

Gary M. Olson and Judith S. Olson
School of Information, University of Michigan, 550 East University Avenue, Ann Arbor, Michigan 48109-1092; e-mail: gmo@umich.edu, jsolson@umich.edu

Key Words groupware, cognitive modeling, ubiquitous computing, usability, social context

■ **Abstract** Human-computer interaction (HCI) is a multidisciplinary field in which psychology and other social sciences unite with computer science and related technical fields with the goal of making computing systems that are both useful and usable. It is a blend of applied and basic research, both drawing from psychological research and contributing new ideas to it. New technologies continuously challenge HCI researchers with new options, as do the demands of new audiences and uses. A variety of usability methods have been developed that draw upon psychological principles. HCI research has expanded beyond its roots in the cognitive processes of individual users to include social and organizational processes involved in computer usage in real environments as well as the use of computers in collaboration. HCI researchers need to be mindful of the longer-term changes brought about by the use of computing in a variety of venues.

CONTENTS

INTRODUCTION

Human-computer interaction (HCI) is the study of how people interact with computing technology. One major area of work in the field focuses on the design of computer systems. The goal is to produce software and hardware that is useful, usable, and aesthetically pleasing. A closely aligned area is the evaluation of systems in use. This is of course related to design, because to know if a design is useful or usable requires observing it in use. However, this also extends to the study of the larger social consequences of use. Increasingly, evaluation takes place at multiple levels of analysis: the individual, the group, the organization, and the industry or societal sector. The methodological and conceptual issues at these different levels of evaluation are quite different. Psychologists are typically most interested in the smaller levels of aggregation, though Landauer (1995) attempted to provide a largely psychological account of the "productivity paradox," a phenomenon first identified by economists who found a disappointing lack of correlation between the amount of money invested in information technology and changes in industry productivity measures.

This chapter updates and expands the last review of HCI in the *Annual Review of Psychology* (Carroll 1997). There has been steady growth in the field since then, and in our brief chapter we can only highlight some of the most significant changes. We also give explicit attention to the emergence of research at the group and organizational level, often referred to as computer-supported cooperative work or CSCW.

The field of HCI is fundamentally interdisciplinary. The fields of cognitive, social, and organizational psychology are all important to research in the area, but other social sciences such as sociology and anthropology have played key roles, as have such related fields as communication, management, operations research, and ergonomics. Also, a variety of technical specialties from computer science are important. Research in HCI requires literacy in the related fields and often involves multidisciplinary collaboration.

Some think of HCI as a purely applied field. However, being applied does not mean lacking in relevance to basic science. Stokes (1997) argued that the quest for fundamental understanding and considerations of use are two separate dimensions of a 2×2 table rather than opposite ends of a continuum. He used Pasteur as an example of research that sought both fundamental understanding and practical solutions. Whereas some research in HCI is close to purely applied, as we hope to show in this review, much of it falls in Pasteur's quadrant.

THE SCIENCE OF HUMAN COMPUTER INTERACTION

Theoretical advances in HCI are proceeding on a number of different fronts. Modeling of the integration of perceptual-cognitive-motor processes to illuminate the moment-by-moment behavior people exhibit with computers has become more detailed. At the more social level, there is work on distributed cognition, focusing on the interplay of people with their teammates and the artifacts of their interaction. Another class of tasks, that of information retrieval, is receiving attention from HCI researchers. What we do not have yet is a detailed model of social interaction or of some of the larger issues of adoption of innovation. There is significant work to be done to understand what might be unique about the adoption of computation as an innovation, because computational artifacts can be designed in so many different ways.

Cognitive Modeling

One of the longer-running cumulative efforts in HCI is the attempt to understand in detail the involvement of cognitive, perceptual, and motor components in the moment-by-moment interaction a person encounters when working at a computer. This effort stands in contrast to a lot of traditional psychological research in that the goal is to understand how multiple components of behavior interact, not just how one works. This line of work began with the now-classic work by Card et al. (1983) in a book called *The Psychology of Human-Computer Interaction*. In this book they catalogued phenomena from the traditional psychological literature that they believed were at play in HCI tasks: Fitt's Law, Hick's Law, Gestalt principles, the Power law of practice, etc. They built a set of models that separated the knowledge needed to use a particular computer application, called GOMS (an acronym made up of its major components: goals, operators, methods, and selection rules), from the engine that operates on this knowledge to produce behavior, called the model human processor. With this approach, one could determine several important behaviors: the time it takes to do a task (the sum of a number of "cognitive engineering time parameters" including mental and physical acts), which choices people will make when faced with alternative methods, what kinds of errors are likely (e.g., loss of items from short-term memory, a motor slip), and how long it will take for someone to learn a new application.

A number of researchers built on this original work, adding parameters of mental and physical action (e.g., Lerch et al. 1989, Nilsen et al. 1993) and modeling detail about the perceptual processes (Lohse 1991), accommodating overlapping mental processes (John & Newell 1989), and more fully detailing the perceptual-motor interplay (Kieras & Meyer 1997) reviewed in Olson & Olson (1990).

The most significant recent advance is the work in which Kieras & Meyer (1997) determined an overarching architecture of component stores and processes, called EPIC (executive process–interactive control), and modeled a far reaching set of phenomena within it. The components of the architecture are shown in Figure 1. This work is a good example of Pasteur's quadrant, work that is both practically driven and adds to fundamental science. By adhering to the agreed-upon architecture, they forced their explanations of various phenomena to cumulate, to illuminate new aspects of the fundamentals of human behavior. They have focused recently on aspects of eye-hand coordination and the extent to which two hands can be used independently. At the same time, they are driven to explain practical phenomena such as the dual-task performance common in operating a car (interacting with the direction-finder interface while negotiating traffic) or making tactical decisions while following a particular target in a military aircraft. In the style of the SOAR modeling community (Laird 2002), the authors have made their

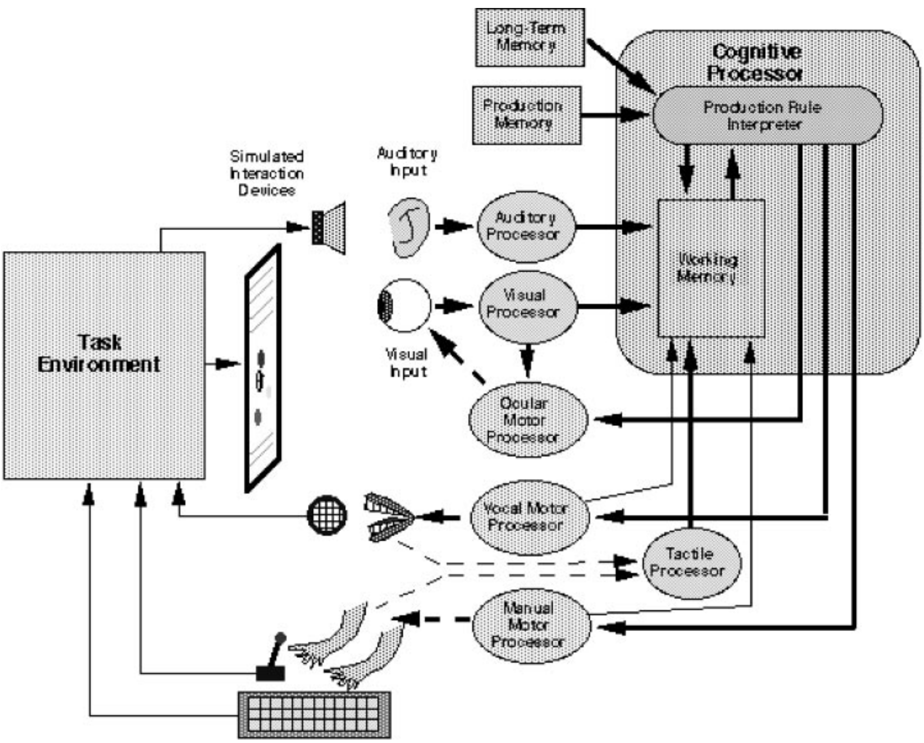

Figure 1 The architectural components included in the EPIC (executive process–interactive control) models of people's behavior with computer applications.

source code available and encourage others to explore both the boundaries of the model and its practical application.

Cognitive modeling has had a number of practical applications. Gray et al. (1993), for example, applied it to the evaluation of two telephone operator keyboards, predicting and confirming empirically that the new keyboard forced a task that required on average 2 seconds longer to enact, an unacceptable performance difference for those considering how many people are needed to staff a large volume of calls. Others have applied cognitive modeling to the design of applications such as a CAD (computer aided design) application and a back-office banking application for deposit slip reconciliation (John 1995). For example, in the back-office banking application the analysis recommended a rearrangement of the visual display so that it required only a single glance to make a comparison rather than multiple glances while also holding information in working memory.

Powerful though this modeling is, it is not universally applicable, nor does it address the full range of questions that appear in the design of computer interfaces. It applies only to skilled users without accounting for how one becomes skilled. Most of the modeling has focused on the more perceptual/motor aspects of tasks (applying it to eye-hand coordination and skilled motor tasks) and less on the more difficult cognitive components (such as those involved in creating a financial model in a spreadsheet application). There are few accounts of individual differences and the role of fatigue and practice in performance. Nor do these models address the larger issues of the fit of the computer system to the goals of work (Olson & Olson 1990).

Distributed Cognition

A second line of theoretical research addresses the more social and contextual aspects of work that the cognitive modeling line does not. This line, called situated cognition or distributed cognition, stems from anthropological and sociological studies of real-world work situations (Olson 1994). It recognizes how people's actions are intimately intertwined with the artifacts of their work; their team member's roles, responsibilities, and actions; and even their cultural and historical setting. This work draws on the methods of ethnography, ethnomethodology, activity theory, and conversational analysis, gathering data from the field instead of the laboratory, generating a number of rich case studies.

The work of Hutchins (1995) is a good example of this work. In his case study he described the ways in which the team in a cockpit engages in the complicated maneuvers involved in landing an aircraft. They collectively prepare their environment so that when the cognitive processing load becomes high in the last moments before landing, they no longer have to make calculations but can merely perceive various settings to trigger actions. For example, they calculate the altitude and speed at which they will have to change the flaps and preset various markers on the cockpit dials. The somewhat complicated calculation is aided by a set of cards that prespecify parameters for various load and weather conditions; the pilot's task is merely to select the appropriate card and post it for others in the cockpit to refer to as they set their parameters and monitor the descent. The close coordination of the individual players' cognitive activities and how they arrange their environment to coordinate actions with others is the key to claiming that the unit of analysis should be the whole system, not the individual. Thus, to understand the behavior of the individuals, one must examine the entire environment in which the activity takes place. "Such factors as the endurance of a representation, the sensory modality via which it is accessed, its vulnerability to disruption, and the competition for modality specific resources may all influence the cognitive properties of such a system" (Hutchins 1995, p. 286).

This line of thinking has inspired a number of design ideas, notably in the design of the work environment. Deep analyses of how people use their desks with its piles of papers and sensitivity to location have led to interfaces that display results of searches in spatial arrangements reflecting some aspect of the material, either its date or content. (Czerwinski et al. 1999). Other analyses of how people work with their whiteboards in both their offices and in meetings led to the development of electronic whiteboards and clever ways to combine electronic and physical artifacts (Moran et al. 1997, Mynatt et al. 1999).

Scope of the Theories

Theories and problems in HCI today parallel some of the theoretical transitions that we witnessed in the 1970s in cognitive science and in the 1960s in verbal learning. The question is, how much of people's behavior can be explained by factors generalizable to all users, regardless of domain expertise or meaning. In the early 1970s in the area of verbal learning, we broke from studying learning of nonsense syllables to learning in richer environments in which meaning was key (Prytulak 1971). In the 1970s there was a lot of work in the spirit of the General Problem Solver (Newell & Simon 1972), attempting to find out the features of people's intellectual processing that were common to everyone, where they relied only on simple general strategies such as hill-climbing and generate-and-test. Soon thereafter, countervailing research focused on the nature of expertise and the specific strategies that experts used rather than generic properties of cognitive processing (e.g., Ericcson & Charness 1994).

In HCI there is a similar transition from understanding generic behavior (Gestalt explanations of the understandability of visual layouts, tradeoffs in using mouse-menu input devices versus learned keystroke combinations) to more knowledge-centered behavior. For example, a recent study of expert/novice searchers of large knowledge sources (such as the World Wide Web) showed that both strategies and successes were highly dependent on domain expertise. The person familiar with medical information sources was much better and faster at confirming the appropriateness of a treatment for a diagnosis than the layman and worse at finding the best price for a consumer product. The search strategies were highly dissimilar and fully dependent on the domain of expertise (Bhavnani et al. 2001).

Human Computer Interaction Work on Information Retrieval

Whereas most of the theory and applications in HCI of the 1980s and early 1990s focused on computationally supported office applications such as word processors and spreadsheets, one of the major theoretical advances of the late 1990s came in an examination of information-retrieval behavior. Spurred by the advent of the World Wide Web and ubiquitous "surfing" behavior, Pirolli & Card (1999) investigated how people decide to continue in a line of searches and when to jump to a different source or search string. To model this behavior they drew on foraging theory from biology. They saw the analogy between the movement of animals from one food source to another (a "patch") and people's movement from one information source to another. They modeled the moment-by-moment decisions people make in their assessment of the value of what they see in search results to predict when they would pop back up to a high level change in a search string or a completely different source such as stopping searching the web and asking a reference librarian. This work also highlighted the importance of the display of the search results in the way it gives clues ("scents") as to whether further selection of an item is likely to be valuable ("to bear fruit"). So, for example, if a Google search returns only headers or urls, it has a less informative "scent" than a display of the sentence fragments that surround the words that match the search string. These bits of information give the user clues as to whether the selection of that item is likely to be useful.

The Card and Pirolli information-foraging work is remarkable not only in its novelty of task and approach, but in the variety of methods they bring to play in their work. They motivate the investigation with some descriptions of real people searching for information—a team of MBAs doing an industry analysis and a consultant writing his monthly report on a topic. From phenomena gleaned from these cases, they worked with mathematical foraging theory, applying various concepts and equations to information rather than food-seeking behavior. Of particular relevance here were calculations on the time a person would spend in a fruitful region of information before moving on to another and the factors that drove the decision to move. They then moved to modeling the moment-by-moment behavior of people conducting their search with an ACT-IF model (the ACT-R model applied to information foraging, IF). The mathematical analyses show aggregate behavioral trends (e.g., average time to linger as a function of richness of the scent), whereas the ACT-IF model allowed them to explore various mechanisms that might account for this behavior. They concluded with an empirical laboratory study of people making such switching decisions in a particular information-retrieval system called the "Scatter/Gather" interface. They made very specific predictions of when someone would stop searching a source (when the average value of a found item dropped below an estimated middle point). They also encouraged designs to give "scent," hints as to the ultimate value of continuing searching on a particular path, such as meaningful labels and revealing search results.

USER INTERFACE DEVELOPMENTS

As computing technology changes, new user interface challenges arise. For instance, in the early days of personal computing screen displays were mostly command lines in green or yellow on a black background. Editing a manuscript included placing explicit formatting characters in the text. With the emergence of graphical user interfaces (GUIs), whole new classes of issues emerged, as well as new opportunities for tapping into key cognitive and perceptual processes. Much of the design of early GUIs was influenced by psychological research (e.g., Johnson et al. 1989). Such systems have been around long enough that they have achieved some level of stability in design, even across different hardware and software platforms.

Now all kinds of new situations are emerging that are challenges to human-computer interaction specialists. We briefly describe some examples of these and indicate the character of some of the psychological issues involved. As applications move from the desktop to more mobile, immersive environments and to a wider set of users, there remain a number of challenges for basic psychology. How do people understand aspects of the digital world as it is embodied in these various devices? How do we capitalize on the strengths of each human, coupling them with assistance from computing, to bring about the most in a productive, satisfying life?

Mobile Devices

In the past decade a wide variety of small mobile devices have appeared. The most common are what are called personal digital assistants or PDAs. These are small handheld devices that have increasingly sophisticated computational capabilities. The user interface challenges are daunting. These devices typically have small screens, and interactions are with a stylus and a small set of buttons. Some models have optional folding keyboards that allow for more traditional interactions. Despite these user interface challenges, such devices have a number of very useful functions and are very popular. Combinations of mobile devices, such as the merging of PDAs and cell phones, are just appearing.

One specialized user interface issue is how to integrate such mobile devices with more traditional computing. For instance, Milewski & Smith (2000) developed a digital address book with location sensors that could be accessed from a regular workstation or from a PDA and that provided information about the availability of others that could be used to coordinate phone calls regardless of where the participants might be. The interface had to be adapted to the capabilities of each device in a way that users found intuitive and natural.

Immersive Environments

Virtual reality environments are artificial 3-D environments created computationally to either mimic a real environment or to create a novel one. These can vary in their immersiveness. The least immersive would be a 3-D environment presented on a computer screen. This could be enhanced by stereo glasses that give a real 3-D experience. Alternatively, the user can wear a head-mounted display for a completely immersive experience. Special rooms such as the CAVE (Cruz-Neira et al. 1992) can surround the user with an immersive experience, with all the surfaces of the room having projected information and with stereo glasses used to create apparent objects that hover in space. Virtual reality environments have been used for a variety of serious as well as playful purposes (see extensive examples in Barfield & Furness 1997).

Collaborative virtual environments are those in which multiple persons interact, either in games or in collaborative activities like data exploration. Because of limitations in computational power, people are usually represented as avatars, simplified, geometric, digital representations of people, who move about in the 3-D space (Singhal 1999). The users in a meeting situation might interact over a digitally represented object, such as a mock-up of a real object (an automobile engine, an airplane hinge, a piece of industrial equipment) or with visualizations of abstract data (e.g., a 3-D visualization of atmospheric data). It has proven difficult to establish mutual awareness or orientation in such spaces, because the small windows do not provide a good sense of where you are (Hindmarsh et al. 1998, Park et al. 2000). There have even been some attempts to merge collaborative virtual environments with real ones, though with limited success so far (Benford et al. 1998).

These virtual environments engage numerous perceptual, cognitive, and social issues. The interface devices for such environments, such as head-mounted displays, wands that allow manipulation and selection of virtual objects, and special data gloves that allow life-like manipulation of virtual objects, all have required extensive human-factors development (Barfield & Furness 1997). A special challenge is integrating such virtual environments with human capabilities to yield enhanced performance and experiences.

Ubiquitous Computing

Weiser (1991) stated, "The most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from it." Through this analysis he forecast what he claimed would be the third wave of computing (after mainframes and personal computers), ubiquitous computing, or as he often called it, ubicomp. This would be when computers would be so small, inexpensive, and ubiquitous that they would disappear. Small computational devices can perform a variety of functions. For example, so-called smart houses have computational devices that can control a variety of functions such as heat, lighting, kitchen appliances, intercoms, entertainment, and telephones. The proliferation of computing devices raises many user interface issues about how to control all of these devices and how to give users adequate flexibility, security, and privacy.

Internet, World Wide Web (WWW)

Although the ubiquity of the Internet and the wealth of information available through it is stunning, the user interface took a giant step backwards from the set of applications people were using before its arrival. There is very little interaction with web sites other than finding and clicking on action buttons that promise continuing good information. Most of the user issues have to do with navigation (how did I get to this site and how do I return to it?), readability of the material presented (font size and color, as well as Gestalt principles of organization), and impatience with long system response times. In order to make sense out of mountains of information in a web site (like the gateway to the University's store of information), designers are borrowing principles from library science, creating a field called information architecture. In information architecture the focus is on the organization, navigation, labeling, and search systems that offer accessibility to the end user (Rosenfeld & Morville 1998). With information architecture coupled with good user interface design principles, there is hope that the users will be better able to realize what information resides in a large web site and then be able to navigate through it to find what they want.

In addition to the design and organization issues are issues of motivation and trust. There are design prescriptions gleaned from empirical studies of web-searching behavior that claim that if in three clicks users do not find information that at least suggests they are on the right track, they will leave the site (Kuegler 2000). This bold prescription harkens to the Card and Pirolli information-foraging theory, making explicit the effort people will expend in an information patch before moving on to another source. Also, when encountering a site for purchasing goods (e.g., Amazon.com) or for getting professional advice (e.g., webMD.com), people need to assess the trustworthiness of the service. Some people are reluctant to enter their credit card information or reveal their illness concerns, whereas others are unconcerned with the potential loss of privacy or even identity theft in these unvetted sites [the *Communications of the Association for Computing Machinery* (CACM) offered a special issue on trust in December 2000]. What is it that makes people trust? How do risk and loss get assessed in the technical world? Do people use the same criteria to assess trust in cyberspace that they do in the physical world?

Extended Populations of Users

Early work on human-computer interaction (HCI) focused little on individual differences. Results were targeted to the educated office worker without disabilities or particular talents. Today there is a healthy interest in interfaces for children and for people with disabilities, including the aging population. Children, for example, have less-well-organized knowledge from which to build metaphorical interfaces, have less-well-developed motor skills, and are interested in new, unsubtle changes in their environment. Design prescriptions follow the recognition of these different capabilities, creating larger and more colorful input devices, heavy use of animation, and explanatory material using speech instead of text (Druin & Soloman 1996).

Interestingly, when conducting usability tests with children, it is impossible to hold their attention span and get them to tell the developer what they do and do not understand. In response to this, knowing that children are very social and interact by talking a lot, usability tests for children are conducted in pairs, allowing them to talk to each other about what ideas they have about how to do things and their guesses about how to get it to work right. Using the natural verbalizations of pairs of children, they achieve what an adult would do under "thinking out loud" instructions.

For people with disabilities there are a number of promising advances. Computers have been outfitted with various input devices that allow people with limited or nonexistent hand motion to enter text. For example, one can speak to a computer that is outfitted with speech recognition devices, and some interfaces show the alphabet one letter at a time, with the user blowing in a tube device when they wish to select that letter. Accompanied with word prediction software tuned to the vocabulary of the user, this device can provide access and "a voice" to people for whom participation with others would be very difficult. There are some interfaces, as well, that are customized to the particular perceptual and motor parameters of the user, in the spirit of GOMS parameters, that then make the interaction maximally efficient for the particular user (Horstman-Koester & Levine 1994).

A number of companies are now also providing "screen readers" to help the visually impaired have access to the very visual web. These are still very unsatisfactory, however, because not enough is understood about how to parse the site to focus on the areas the user wants to attend, not reading the whole screen top down, left to right. By encoding hidden tags in the html, designers can make their sites accessible to the visually impaired through screen readers if they understand the reader's algorithms and the needs of the user to scan and understand the screen. Some web sites provide an automatic evaluation of the visual accessibility of target web sites, giving advice on how to make them more accessible (a portal of these sites is available at http://www.c2t2.ca/landonline/access.html#newtech).

Other advances are making actions and content of applications fit those in non–North American cultures as well. It is simple to think of translating the menu items or the site contents into other languages, but cultural disparities likely require changes more fundamental than simple surface characteristics. For example, icons such as a red cylindrical mailbox, common in the UK, may not be understood by those in other cultures. Also, templates for memos, presentations, etc. would have to be altered to better fit the conversational conventions of the culture (del Galdo & Nielsen 1996).

USABILITY METHODS

The practitioners in the field of HCI, called user-experience engineers (UEEs), use a variety of methods to generate and evaluate applications (details of which appear in Olson & Moran 1996, including extensive references). When they are on the team that generates the functionality of the system, a role sometimes left only to marketing analysts, they employ various methods that closely investigate the setting in which the target users reside, their current activity, and their culture and capabilities. They use contextual design (Beyer & Holtzblatt 1998) and participatory design methods (Muller 1991), which differ only in whether the target users are directly involved in the design or merely consulted about their activity and preferences. Both employ interview and observation techniques, sometimes as deep as ethnography, sometimes not, depending on the time and resources of the project.

In the process of design itself, UEEs employ a number of methods, called formative evaluation. There are very few methods that focus on the design process other than mere lists of design principles. There are a number of methods that help the designer evaluate the prototype design. Among them are the informal use of various checklists, the more formal inspection methods called heuristic evaluation (Nielsen 1993) and cognitive walkthrough (Lewis et al. 1990), and claims analysis (Carroll & Rosson 1992). Each of these inspection techniques goes through the prototype from the user's perspective, attempting to notice those aspects that will cause difficulty for the user, such as having nonobvious words indicate the next action to take, unreadable color combinations, or unexpected locations for next actions. Because these methods do not take a long time and typically involve only two or three expert evaluators, they have received a lot of attention and adoption. When the design is intended to support repetitive tasks with skilled users (e.g., telephone operators or reservations clerks), some employ either the GOMS or keystroke-level analysis to assess various aspects of cognitive load and expected duration of the task (Gray et al. 1993). Such analyses have shown, for example, where a designed task was flawed because it required too much information to be held in working memory for too long, creating a situation ripe for errors.

UEEs who follow recommended practice then evaluate the prototype with a usability test, an activity that is similar to standard psychology experiments. Instead of comparing two or more conditions, the usability test focuses on episodes in task behavior in which the user has difficulty, either pausing longer than expected or making outright errors (Rubin 1994). Some of these usability tests are used to indicate corrections to be made to the application, some are used to assess whether the application is good enough to either implement to real users or to launch in the market.

Early in the 1990s the HCI community engaged in a debate about the cost/benefit of the above listed methods. For example, it is well known that usability tests are expensive in time and expert resources, whereas some of the inspection methods are much less time and resource intense. Similarly, doing a detailed GOMS analysis was thought to require a great deal of expert time and yield no more insights than other more cursory inspection methods. A number of studies then compared the efficacy of various methods on how many and how severe the design issues were that the evaluators could find (e.g. Jeffries et al. 1991, Karat et al. 1992, John & Kieras 1996). Gray & Salzman (1998) criticized these studies for their departure from good experimental design, saying conclusions were unwarranted from the power and control in their designs. The paper sparked a debate among the authors of the original evaluations plus others who have experience with the methods, countering Gray & Salzman's claims that the studies were useless in guiding decisions about which method to use (Olson & Moran 1998). The general consensus, however, is that the inspection methods find a number of design issues, but not all, and are less expensive than running a usability test with real users. The usability tests are good at finding the "show stopper" issues, the points where the user cannot understand the words or paragraphs intended to inform them about what to do. The simple prescription is to do as much evaluation as time and resources allow, and that designs benefit greatly from having at least one real user test the system.

A recent interview study showed there are increasing numbers of UEEs on staff in organizations that build either products for the external market or applications for internal use (Olson 2001). Early usability professionals came to this position with PhDs in psychology or industrial engineering. Today, although those in HCI research have PhDs, there are many UEEs who have masters' degrees in HCI (See http://www.hcibib.org/education/ for a listing of the university programs that offer degrees in HCI). Some larger organizations, understanding the value of usability and functionality in the marketplace, employ a large number of UEEs; IBM, for example, has over 1000. As a community they have a large internal network of expertise and even hold their own internal conference to share their findings and design ideas. Most of the UEEs are heavily involved in both original design and iterative evaluation of applications, some in determining the functionality of the proposed system, and only a few in the decision to launch a system.

The profession is well established and in many organizations enjoys respect for their contribution to making usable products and services and increasing customer satisfaction. There is still a need for better design methods, and perhaps an infusion of usability criteria into the software engineering curriculum. It would be more effective if developers had the sensibilities of user needs and capabilities themselves, rather than having to have usability specialists on a team to work in partnership with the developer.

THE WORKPLACE

As noted in "The Science of Human Computer Interaction" above, much of the early work in HCI focused on productivity tools such as word processing, spreadsheets, databases, calendars, and so forth, but these were mostly studied in isolation from actual work. Issues such as the naming of commands, the layout of screens, the organization of menus, the flow of action sequences, and consistency were examined and behavior was measured on representative but isolated tasks in a laboratory setting. More recently, however, investigators have been interested in the nature of the workplace and in the role of computers in the larger organizational and economic context. In more psychological terms, the shift has been from a perceptual/cognitive perspective to a social/organizational one.

One such line of work has investigated the "productivity paradox." As perhaps described most elegantly by Strassmann (1990), for a long time it has been difficult to show a relationship between investments in computing and measures of productivity. Strassmann presented scatterplots of these two variables that are canonical versions of a zero correlation coefficient. There have been numerous attempts to explain this, but one that is relevant to HCI is Landauer's (1995) argument that the productivity paradox is due primarily to the poor utility and usability of systems. He argued that more widespread use of user-centered development methods could turn this whole situation around. More recent work by Brynjolfsson & Hitt (1998) suggests that computing may at last be producing some measurable gains in productivity and that better-designed systems as well as organizational adjustments may be key.

Some of these changes in the effectiveness of computer tools can be seen with respect to specific tools. In Grudin's (1988, 1994) famous exposé of the early widespread failures of computer-supported cooperative work (CSCW) technologies, he singled out group calendaring as a specific example of poor fit into organizations. These conclusions were based on studies carried out in the early 1980s. In a recent survey of the successful adoption of group calendaring in several organizations, Palen & Grudin (2002) observed that organizational conditions in the 1990s were much more favorable for the adoption of group tools than they were in the 1980s. Individuals found more personal value in being on a calendar, and there was increased social pressure from colleagues after a critical mass of adoption was achieved. Further, the tools themselves had improved in reliability, functionality, and usability.

COMPUTER SUPPORTED COOPERATIVE WORK

One manifestation of the expansion of attention to the group and organizational levels of analysis is the emergence of CSCW as a field. The first conferences on CSCW were held in the United States in 1986 and in Europe in 1989, but the area really flourished in the 1990s. Numerous systems were developed to support human interaction in all combinations of same/different time/place. The human use of such systems involves a wide variety of psychological issues, particularly from social and organizational psychology. We briefly review some representative examples and refer the reader to a more extensive review of this work by Olson & Olson (2002).

E-mail

E-mail has become a universal service just like the telephone (Anderson et al. 1995), often noted as the first successful groupware application (Sproull & Kiesler 1991, Satzinger & Olfman 1992, O'Hara-Devereaux & Johansen 1994, Anderson et al. 1995). With the more recent addition of attachments, people share not only plain text conversation but work objects as well (Garton & Wellman 1995). With this wide adoption have come social consequences. E-mail has widened connectivity to people who previously did not communicate with each other (Sproull & Kiesler 1991). It has given a voice to people who were previously unheard from in discussions (Finholt et al. 1990). Because the speaker does not get feedback from the listener, shy people are more likely to voice their opinions. However, this same lack of social cues has caused people to "flame," to send more extremely emotive messages than they would have done with the immediate social feedback of face-to-face encounters. Although some of this effect is abating with experience, it is still a concern as new users join in the e-mail culture (Hollingshead et al. 1993, Arrow et al. 1996).

The ease of communication and broadcast that e-mail has provided has produced another social consequence, information overload. Some developers have employed techniques from artificial intelligence to block or sort incoming e-mail but have had limited success. It remains difficult to specify the rules of sorting/blocking in sufficient detail to perfectly sort the wanted from the unwanted (Malone et al. 1988, Winograd 1988). Today, successful handling of the overload involves substantial human intervention (Whittaker & Sidner 1996).

Meeting Support

Shared workspaces are very important in meetings, and a number of shared workspace applications have been created to support meetings. Simple group editors are very effective for free-flowing meetings such as design meetings or brainstorming sessions (Olson et al. 1993). People produced higher-quality work than when using standard whiteboards and paper and pencil but, likely because the technology was new, were less satisfied with the process. They may not yet have learned how to interact with each other and to have their opinions heard or to have decisions come out the way they want them to. The supported meetings also had less verbal discussion, because the growing artifact (e.g., the proposal or report workers were co-constructing) served as a medium of exchange as well as their voice commentary (Clark & Brennan 1991). People reported liking the meetings because work was accomplished in the meeting; the time was not just spent talking about the work.

Some have taken the idea of shared digital objects and displayed them on electronic whiteboards. These whiteboards are large projection surfaces into which people have input by light-pen or through a touch-sensitive screen (Elrod et al. 1992). Several extended case studies of their use give us insight into how people adopt and adapt to their features. Studies at Xerox PARC (Palo Alto Research Center) and at Boeing showed that people value the electronic whiteboards because they could all see and agree to or discuss further proposed changes, even those that require some computation (e.g., a spreadsheet of salary adjustments whose sum cannot exceed a specific fixed amount). Some of these whiteboards were even programmed to handle the implicit structure that appears in the spatial layout of freehand writing. For example, the LiveBoard at Xerox recognized handwritten lists and outlines, allowing easy edits that preserved and used the inherent structure of the display (Moran et al. 1996).

Other meeting support tools take the computational power much further in support of various aspects of meetings. Group-decision support systems embody various brainstorming and voting procedures (Nunamaker et al. 1991). Participants enter their ideas into a central repository in parallel, and evaluate others' ideas in attached comments. Aggregates of individuals' opinions are displayed, triggering additional discussion and refinement. Different voting mechanisms help the decision makers combine their assessments and votes. Evaluation of these systems showed that their use generated more ideas from participants, because they didn't have to wait for one another to stop speaking in order to get a turn. They felt, too, that anonymous voting and rating helped to insure equal participation, not dominated by those in power. However, decisions were not rated as satisfying, and the meetings took longer than normal ones (Kraemer & Pinsonneault 1990, McLeod 1992, Hollingshead et al. 1993).

Supported meetings are slow to penetrate normal organizational life. The literature has shown quite clearly that these meetings produce better outcomes. However, these tools require a new way of working, and people are reluctant to learn new ways of negotiating with each other and getting their ideas heard. As cost of these systems comes down and more people gain experience with them, it will be interesting to see what factors contribute to or detract from easy adoption.

Conferencing Tools: Voice and Video

Those who must coordinate over long distances often use audio- or videoconferencing. Typically special videoconferencing rooms are built linked with high bandwidth connections and compatible camera and projection systems. Some more recent advances in technology have made the capability much cheaper (video over the Internet) and the systems much more interoperable, making the cost reduction sufficient for people to more widely adopt it.

Quality is still an issue, however. When the audio stream is sent with the video, the combined signal is delayed usually on the order of a second, a significant enough delay to disrupt normal conversation. Many experienced videoconference participants know to supplement the video with a standard telephone connection to support immediate voice signals with the additional feature of full-duplex so participants can hear the "backchannel" responses while the speaker speaks (Finn et al. 1997). Also, some technologies that compress and decompress the video stream alter the picture so that people appear to have jerky actions. Because unusual actions are a signal that someone is lying, one can make mistakes in attributing truthfulness merely because of features of the transmission channel (Horn 2001).

These technologies have afforded some good support for remote meetings. In a controlled comparison of meetings with video connectivity and those in which people are collocated, the quality of the work was the same. However, the remote groups were less satisfied with the quality of the discussion, and it took attention to orchestrate their work more than those who were collocated (Olson et al. 1995). Not all groups need video, however. A second study showed that those who know each other well and have a lot of common ground work just as well with audio; strangers or those without common ground benefit most from having video as well as audio (Veinott et al. 1999).

Instant Messaging, Chat, MUDs

With the advent of instant messaging applications like those offered by America Online's AIM, Microsoft's MSN Messenger, and ICQ ("I seek you"), people have the ability to instantly converse with each other through text in real time. When the relay time is short, these interactions can feel like real conversations. Users specify to whom they would like to reveal whether they are on-line through a "buddy list." Symbols next to the list of participants shows who is on-line, who is "away," and who has signed off. This combines awareness of others' activity state as well as access in real time for informal, immediate responses. Although these are very popular among teens, they have also been used effectively in the workplace (Nardi et al. 2000). Babble is a chat system that has been used at IBM for discussions, with a clever graphical display of others' activities for awareness (Erickson et al. 1999).

Some chat systems allow large numbers of participants to converse, with all contributions being shown in one window in chronological order. The question is whether this mixture of conversation threads is difficult for the participants to follow. An evaluation comparing the confusion people have in a chat system with those in face-to-face encounters showed no extra difficulties, even though many more people were participating than normally do in a meeting. People added a few clues to help others keep track of the threads, however, such as reference to names they are responding to and explicit references to the topic in their responses (McDaniel et al. 1996).

A richer form of chat comes in what is called MUDs (derived from Multi-User Dungeons and Dragons, an early multiparty game). MUDs include rapid interchange of conversation interlaced with descriptions of virtual places, objects, and emotions. For example, one can enter a contribution about an action or the state of one's emotion ("Gary enters the room." "Judy smiles.") Also, objects play in the interchange, often having "magical" properties, awarding the recipient with various powers or gifts. There have been examples of MUDs in work settings, such as Waterfall Glen at the Argonne National Lab (Churchill & Bly 1999). Turkle (1995) looked at a number of psychosocial aspects of MUDs, focusing in particular on identity.

Awareness

When people are collocated, they have numerous opportunities to assess whether teammates are available for conversation, what they are working on, etc. Simple glances into people's offices while walking to the printer give a lot of information about their state. People working remotely have no natural source of such information. Various technology solutions have been offered: Video glances into offices (Fish et al. 1993, Bellotti & Dourish 1997) and periodic snapshots instead of full-motion video (Dourish & Bly 1992) were offered at some work settings. However, because many felt these to be more invasive of their privacy than simple walk-bys at the office, these systems have not been widely adopted. The places where these systems succeed are those where the individuals seem to have a reciprocal need to be aware of each other's presence, and they have a sense of cooperation and coordination. Instant messaging systems, on the other hand, seem to be more widely accepted because they allow the users to control what information they are broadcasting to others, and the signal is much less informative about exactly what they are doing. Nardi and her colleagues (2000) found that people liked this aspect of instant messaging. In all of these monitoring applications, awareness and calendaring alike, the issues of trust and privacy loom large (see Godefroid et al. 2000).

Group Calendars

Remote team members work asynchronously with e-mail and attachments and synchronously using chat or video/audio conferencing and shared workspaces. The major technologies to support the transitions from one mode to the other are electronic calendars. In group calendars, participants keep their schedules online in a place that is accessible (for read/write or just read permission) to others they designate. By seeing each other's calendars, it is easier to find times to meet that fit most people's schedules. As such, it is a classic case of misaligned motives: One has to make the effort to enter one's calendar so others may benefit by scheduling one's time (Grudin 1988). Indeed, group calendars were not widely adopted when they first came out. However, with time people have seen how giving to the common good benefits them individually as well, and group calendars are more widely adopted today (Grudin & Palen 1995, Mosier & Tammaro 1997, Palen & Grudin 2002). Apparently such success builds on a culture of sharing and accessibility, something that exists in some organizations and not others (Ehrlich 1987, Lange 1992).

Repositories of Shared Knowledge

In most organizations people share their reports, meeting minutes, customer contacts, etc. in order to coordinate their activities. Modern applications such as Lotus Notes help people to do this in the digital world. People are encouraged to share informal information as well as the more structured formal material, such as new ideas or thoughts, boilerplate for reports, proposal drafts, etc. Unfortunately, these systems are not always successful in gathering shared information. Often, like the case with calendaring, the person who expends the effort to enter information is not always the one that benefits from it. Motivations are misaligned. In fact, in one large consulting firm, the sharing failed outright because the incentive scheme rewarded individual prowess, not group productivity (Orlikowski & Gash 1994).

In organizations in which such a repository has been successful, the incentives were better aligned.

The Web of course provides marvelous infrastructure for the creation and sharing of information repositories. Lotus Notes is now widely used in its Web version, Domino. Environments for sharing such as Worktools (worktools.si.umich.edu) are built on top of Notes. Document management tools such as WebEx (www.webex.com) make it easy to share in a web environment. Systematic research on the use of such improved tools is needed.

Social Filtering

In addition to more-formal sources of information, people use their colleagues for advice and recommendations. One's social network is a rich source of information; the only barrier is finding out who knows what and then asking and receiving an answer. Technological substitutes for this have resulted in "recommender systems." When booksellers such as Amazon recommend books to us, they are using a system that matches one's interests (indicated by previous purchases) with others who have similar purchase profiles. Items the second customer has purchased are then recommended to the first. There is no content analysis here, merely statistical analysis of like people and storage of purchases. A 1997 issue of the *Communications of the Association for Computing Machinery* described and evaluated various systems (Resnick & Varian 1997). The systems that were more acceptable to users were those that explained the choices, not merely listed them (Herlocker et al. 2000). This is an example of the role that trust plays in electronic commerce interactions, a point we discuss next.

Trust of People Via the Technology

It has been said that "trust needs touch" (Handy 1995), and indeed in survey studies, co-workers report that they trust those who are collocated more than those who are remote (Rocco et al. 2000). Those who spend more time discussing nonwork topics with each other, especially on the telephone, trusted their remote colleagues more than those who merely conveyed work-related material by fax and e-mail. However, mere use of the telephone is not the answer. If the only contact people have with each other is over the telephone, they behave in less trusting ways than if they meet face-to-face (Drolet & Morris 2000).

Are there any remedies to this loss of trust over distance? Conventional wisdom says that people should meet face-to-face before conducting work, a result that has been confirmed empirically (Rocco 1998). Zheng et al. (2002) found that it was not necessary to meet beforehand, if instead they communicated about social and personal issues using chat. Exchanging photographs was also effective in increasing trust, whereas merely sharing a resume did not. Bos et al. (2002) reported that richer communication channels such as video and audio facilitated trust formation. Before we get too optimistic about these remedies, however, we should be cautious. Conversation through video is not like "being there." There is no opportunity for the incoming and departure conversations, one has less common ground because the culture and setting of the far location is intrinsically different, and technology can distort how people appear to each other, either too quiet, too tall, or even ill looking (Huang et al. 2002). There is a rich opportunity to study impression formation in these technology-altered settings.

Collaboratories

A collaboratory is a laboratory without walls (Finholt & Olson 1997), and as such is a novel organizational form of considerable interest. From a National Research Council report, a collaboratory is supposed to allow "... the nation's researchers [to] perform their research without regard to geographical location—interacting with colleagues, accessing instrumentation, sharing data and computational resources [and] accessing information in digital libraries" (National Research Council 1993, p. 7). Starting in the early 1990s these capabilities have been configured into support packages for a number of specific sciences (see review in Finholt 2002). For example, the Upper Atmospheric Research Collaboratory (Olson et al. 2001) provided space scientists with access to geographically remote instruments as well as each other through a simple chat facility. This allowed scientists from all over the world to participate in collaborative studies using these remote instruments from their home institutions.

A number of companies have also experimented with similar concepts, calling them "virtual collocation." The goal is to support geographically dispersed teams as they carry out product design, software engineering, financial reporting, and almost any business function. In these cases suites of off-the-shelf groupware tools have been particularly important and have been used to support round-the-clock software development among overlapping teams of engineers in time zones around the world (Carmel 1999). There have been a number of such efforts, and it is still unclear as to their success or what features make their success more likely (Olson & Olson 2000).

Collaboratories are of interest to psychologists for two broad classes of reasons. First, as an emerging organizational form, they provide an example of a novel way of organizing in which the usual factors such as communication flows, trust, establishment of common goals, and motivation can be investigated. Second, of course, they provide a new infrastructure for the conduct of psychological research itself. Early collaboratory efforts have been concentrated in the physical and biological sciences, but the concept should be readily used by social scientists as well.

THE LARGER SOCIAL CONTEXT

Computers are rapidly becoming an ordinary aspect of most people's lives. In September of 2001 (U.S. Dep. Commerce 2002), 56.5% of U.S. households had at least one computer, and 50.5% had Internet access. Sixty-seven percent of individuals (as opposed to households) used a computer at home, school, or work. Thus, for at least two-thirds of the U.S. population a computer has become a regular part of their daily lives.

What are the broader psychological effects of computer use? Kraut et al. (1998) reported that greater Internet use, which in their sample was mostly e-mail, led to declines in social interactions with family members and an increase in depression and loneliness. Not surprising, these results triggered widespread discussion and debate, both over the substance of the results and the methods used to obtain them. Recently, Kraut et al. (2002) reported new results that suggest these initial effects may not persist. Interpersonal communication is one of the principal uses of the Internet, and the possible implications of this kind of communication for social life is important to understand. Indeed, Putnam (2000) has wondered whether the Internet can be a source of social cohesiveness. These kinds of questions need to be addressed by additional large-scale studies of the kind carried out by Kraut and his colleagues.

Another concern is the unequal distribution of computing resources. Disaggregating the overall figures on computer and Internet access by income, by ethnic origin, and by presence of disabilities shows clearly that routine computer access is predominantly a characteristic of urban upper-middle-class white families without disabilities. To take just one example, in 2001 Internet use by whites and Asian Americans was around 60%, whereas for blacks it was 40% and for Hispanics 32% (U.S. Dep. Commerce 2002). The growth of access by minorities is encouraging, but they still lag far behind their majority peers. What are the psychological and social costs of this digital divide? We do not yet have clear answers.

SUMMARY AND CONCLUSIONS

As computing technology penetrates our workplaces, homes, schools, community organizations, automobiles, and aircraft, literally every element of our daily lives, having technology that is useful and usable is of paramount importance. Thus, the field of HCI is at the center of the evolution of effective tools to improve the quality of our lives. As the work by Kraut et al. (1998) hints, we should not naively assume that useful and usable technology is going to lead to positive social consequences. As Sproull & Kiesler (1991) pointed out, we tend to design and deploy technology hoping for immediate efficiency gains but ignoring the longer-term, second-order effects that may be more profound and may be undesirable. In the early days of television the optimists talked of civic enlightenment, widespread education, and wholesome entertainment. Few foresaw that it would actually erode social capital, leading to less civic participation, less involvement with family, higher crime rates, and declines in health (Putnam 2000). As psychologists we need to focus on both the immediate issues of design and effectiveness and the longer-term consequences for individual and social behavior.

ACKNOWLEDGMENTS

Preparation of this chapter was facilitated by several grants from the National Science Foundation (ATM-9873025, IIS-9977923, IIS-0085951). Dan Horn made useful comments on an earlier draft.

The *Annual Review of Psychology* is online at http://psych.annualreviews.org

LITERATURE CITED

Anderson RH, Bikson TK, Law SA, Mitchell BM. 1995. *Universal Access to E-mail: Feasibility and Societal Implications*. Santa Monica, CA: Rand

Arrow H, Berdahl JL, Bouas KS, Craig KM, Cummings A, et al. 1996. Time, technology, and groups: an integration. *Comput. Support. Coop. Work* 4:253–61

Barfield W, Furness TA, eds. 1997. *Virtual Environments and Advanced Interface Design*. New York: Oxford Univ. Press

Bellotti V, Dourish P. 1997. Rant and RAVE: experimental and experiential accounts of a media space. In *Video-Mediated Communication*, ed. KE Finn, AJ Sellen, SB Wilbur, pp. 245–72. Mahwah, NJ: Erlbaum

Benford S, Greenhalgh C, Reynard G, Brown C, Koleva B. 1998. Understanding and constructing shared spaces with mixed-reality boundaries. *ACM Trans. Comput.-Hum. Interact.* 5:185–223

Beyer H, Holtzblatt K. 1998. *Contextual Design: Defining Customer-Centered Systems*. San Francisco: Kaufmann

Bhavnani S, Drabenstott K, Radev D. 2001. *Towards a unified framework of IR tasks and strategies*. Presented at 2001 ASIST Annu. Meet., Washington, DC

Bos N, Olson J, Gergle D, Olson G, Wright Z. 2002. Effects of four computer-mediated communications channels on trust development. In *Proc. CHI (Comput. Hum. Interact.) 2002*, pp. 135–40. New York: ACM Press

Brynjolfsson E, Hitt LM. 1998. Beyond the productivity paradox. *Commun. ACM* 41(8):49–55

Card SK, Moran TP, Newell A. 1983. *The Psychology of Human-Computer Interaction.* Hillsdale, NJ: Erlbaum

Carmel E. 1999. *Global Software Teams*. Upper Saddle River, NJ: Prentice-Hall

Carroll JM. 1997. Human-computer interaction: psychology as a science of design. *Annu. Rev. Psychol.* 48:61–83

Carroll JM, Rosson MB. 1992. Getting around the task-artifact cycle: how to make claims and design by scenario. *ACM Trans. Inf. Syst.* 10:181–212

Churchill E, Bly S. 1999. It's all in the words: supporting work activities with lightweight tools. In *Proc. GROUP 1999*, pp. 40–49. New York: ACM Press

Clark HH, Brennan SE. 1991. Grounding in communication. In *Perspectives on Socially Shared Cognition*, ed. L Resnick, JM Levine, SD Teasley, pp 127–49. Washington, DC: APA

Cruz-Neira C, Sandin D, DeFanti T, Kenyon R, Hart J. 1992. The CAVE: audio visual experience automatic virtual environment. *Commun. Assoc. Comput. Mach.* 35(6):65–72

Czerwinski M, Dumais S, Robertson G, Sziadosz S, Tiernan S, van Dantzich M. 1999. Visualizing implicit queries for information management and retrieval. In *Proc. CHI (Comput. Hum. Interact.) 1999*, pp. 560–67. New York: ACM Press

del Galdo E, Nielsen J, eds. 1996. *International User Interfaces.* New York: Wiley

Dourish P, Bly S. 1992. Portholes: supporting awareness in a distributed work group. In *Proc. CHI (Comput. Hum. Interact.) 1992*, pp. 541–47. New York: ACM Press

Drolet AL, Morris MW. 2000. Rapport in conflict resolution: accounting for how nonverbal exchange fosters coordination on mutually beneficial settlements to mixed motive conflicts. *J. Exp. Soc. Psychol.* 36:26–50

Druin A, Solomon C. 1996. *Designing Multimedia Environments for Children.* New York: Wiley

Ehrlich SF. 1987. Strategies for encouraging successful adoption of office communication systems. *ACM Trans. Off. Inf. Syst.* 5:340–57

Elrod S, Bruce R, Gold R, Goldberg D, Halasz F, et al. 1992. LiveBoard: a large interactive display supporting group meetings, presentations, and remote collaboration. In *Proc. CHI*

(Comput. Hum. Interact.) 1992, pp. 599–607. New York: ACM Press

Ericcson KA, Charness N. 1994. Expert performance: its structure and acquisition. *Am. Psychol.* 49:725–47

Erickson T, Smith DN, Kellogg WA, Laff MR, Richards JT, Bradner E. 1999. Socially translucent systems: social proxies, persistent conversation, and the design of 'babble'. In *Proc. CHI (Comput. Hum. Interact.) 1999*, pp. 72–79. New York: ACM Press

Finholt TA. 2002. Collaboratories. In *Annual Review of Information Science and Technology*, ed. B Cronin, 36:73–108. Medford, NJ: Inf. Today, Inc.

Finholt TA, Olson GM. 1997. From laboratories to collaboratories: a new organizational form for scientific collaboration. *Psychol. Sci.* 8:28–36

Finholt T, Sproull L, Kiesler S. 1990. Communication and performance in ad hoc task groups. *Intellectual Teamwork: Social and Technological Foundations of Cooperative Work*, ed. J Galegher, R Kraut, C Egido, pp. 291–325. Hillsdale, NJ: Erlbaum

Finn K, Sellen A, Wilbur S, eds. 1997. *Video-Mediated Communication*. Hillsdale, NJ: Erlbaum

Fish RS, Kraut RE, Root RW, Rice RE. 1993. Video as a technology for informal communication. *Commun. ACM* 36(1):48–61

Garton L, Wellman B. 1995. Social impacts of electronic mail in organizations: a review of the research literature. In *Communication Yearbook*, ed. BR Burleson, 18:434–53 Thousand Oaks, CA: Sage

Godefroid P, Herbsleb JD, Jagadeesan LJ, Li D. 2000. Ensuring privacy in presence awareness systems: an automated verification approach. In *Proc. Comput.-Support. Coop. Work 2000*, pp. 59–68. New York: ACM Press

Gray WD, John BE, Atwood ME. 1993. Project Ernestine: validating a GOMS analysis for predicting and explaining real-world task performance. *Hum.-Comput. Interact.* 8:237–309

Gray WD, Salzman MC. 1998. Damaged merchandise? A review of experiments that compare usability evaluation methods. *Hum.-Comput. Interact.* 13:203–61

Grudin J. 1988. Why CSCW applications fail: problems in the design and evaluation of organizational interfaces. In *Proc. Comput.-Support. Coop. Work 1988*, pp. 85–93. New York: ACM Press

Grudin J. 1994. Groupware and social dynamics: eight challenges for developers. *Commun. ACM* 37(1):92–105

Grudin J, Palen L. 1995. Why groupware succeeds: discretion or mandate? In *Proc. Eur. Conf. Comput. Support. Work '95*, pp. 263–78. Dordrecht, The Netherlands: Kluwer

Handy C. 1995. Trust and the virtual organization. *Harv. Bus. Rev.* 73(3):40–50

Herlocker JL, Konstan JA, Riedl J. 2000. Explaining collaborative filtering recommendations. In *Proc. Comput.-Support. Coop. Work 2000*, pp. 241–50. New York: ACM Press

Hindmarsh J, Fraser M, Heath C, Benford S, Greenhalgh C. 1998. Fragmented interaction: establishing mutual orientation in virtual environments. In *Proc. Comput.-Support. Coop. Work 1998*, pp. 217–26. New York: ACM Press

Hollingshead AB, McGrath JE, O'Connor KM. 1993. Group performance and communication technology: a longitudinal study of computer-mediated versus face-to-face work. *Small Group Res.* 24:307–33

Horn D. 2001. Is seeing believing? Detect deception in technologically mediated communication. In *Proc. CHI (Comput. Hum. Interact.) 2001*, pp. 297–98. New York: ACM Press

Horstman-Koester H, Levine S. 1994. Learning and performance of able-bodied individuals using scanning systems with and without word prediction. *Assist. Technol.* 6:42–53

Huang W, Olson JS, Olson GM. 2002. Proximity and camera angle in video-mediated communication. In *Proc. CHI (Comput. Hum. Interact.) 2002.* New York: ACM Press

Hutchins E. 1995. How a cockpit remembers its speed. *Cogn. Sci.* 19:265–88

Jeffries R, Miller JR, Wharton C, Uyeda KM.

1991. User interface evaluation in the real world: a comparison of four techniques. In *Proc. CHI (Comput. Hum. Interact.) 1991*, pp. 119–24. New York: ACM Press

John BE. 1995. Why GOMS? *Interactions* 11(4):80–89

John BE, Kieras DE. 1996. Using GOMS for user interface design and evaluation: which technique? *ACM Trans. Comput.-Hum. Interact.* 3:320–51

John BE, Newell A. 1989. Cumulating the science of HCI: from S-R compatibility to transcription typing. In *Proc. CHI (Comput. Hum. Interact.) 1989*, pp. 109–14. New York: ACM Press

Johnson J, Roberts TL, Verplank W, Smith DC, Irby CH, et al. 1989. The Xerox Star: a retrospective. *IEEE Comput.* 22(9):11–29

Karat CM, Campbell R, Fiegel T. 1992. Comparison of empirical testing and walkthrough methods in user interface evaluation. In *Proc. ACM CHI (Comput. Hum. Interact.) 1992 Conf. Hum. Factors Comput. Syst.*, pp. 397–404. New York: ACM Press

Kieras DE, Meyer DE. 1997. A computational theory of executive control processes and human multiple-task performance. Part I. Basic mechanisms. *Psychol. Rev.* 104:3–65

Kraemer KL, Pinsonneault A. 1990. Technology and groups: assessments of empirical research. In *Intellectual Teamwork: Social and Technological Foundations of Cooperative Work*, ed. J Galegher, R Kraut, C Egido, pp. 373–405. Hillsdale, NJ: Erlbaum

Kraut R, Kiesler S, Boneva B, Cummings J, Helgeson V, Crawford A. 2002. Internet paradox revisited. *J. Soc. Issues* 58:49–74

Kraut R, Patterson M, Lundmark V, Kiesler S, Mukopadhyay T, Scherlis W. 1998. Internet paradox: a social technology that reduces social involvement and psychological well-being. *Am. Psychol.* 53:1017–31

Kuegler T. 2000. *Make Your Site a Better Information Delivery Tool*. http://www.clickz.com/design/site_design/article.php/822901

Laird J. 2002. *SOAR Home Page*. http://ai.eecs.umich.edu/soar/

Landauer TK. 1995. *The Trouble with Computers: Usefulness, Usability, and Productivity*. Cambridge, MA: MIT Press

Lange BM. 1992. Electronic group calendaring: experiences and expectations. In *Groupware*, ed. D Coleman, pp. 428–32. San Mateo, CA: Kaufmann

Lerch FJ, Mantei M, Olson JR. 1989. Skilled financial planning: the cost of translating ideas into action. In *Proc. CHI (Comput. Hum. Interact.) 1989*, pp. 121–26. New York: ACM Press

Lewis C, Polson PG, Wharton C, Rieman J. 1990. Testing a walkthrough methodology for theory-based design of walk-up-and-use interfaces. In *Proc. CHI (Comput. Hum. Interact.) 1990*, pp. 235–42. New York: ACM Press

Lohse G. 1991. A cognitive model for the perception and understanding of graphs. In *Proc. CHI (Comput. Hum. Interact.) 1991*, pp. 137–44. New York: ACM Press

Malone TW, Grant KR, Lai KY, Rao R, Rosenblitt DA. 1988. The information lens: an intelligent system for information sharing and coordination. In *Technological Support for Work Group Collaboration*, ed. MH Olson, pp. 65–88. Hillsdale, NJ: Erlbaum

McDaniel SE, Olson GM, Magee JS. 1996. Identifying and analyzing multiple threads in computer-mediated and face-to-face conversations. In *Proc. Comput.-Support. Coop. Work 1996*, pp. 39–47. New York: ACM Press

McLeod PL. 1992. An assessment of the experimental literature on electronic support of group work: results of a meta-analysis. *Hum.-Comput. Interact.* 7:257–80

Milewski AE, Smith TM. 2000. Providing presence cues to telephone users. In *Proc. Comput.-Support. Coop. Work 2000*, pp. 89–96. New York: ACM Press

Moran TP, Chiu P, Harrison S, Kurtenbach G, Minneman S, van Melle W. 1996. Evolutionary engagement in an ongoing collaborative work process: a case study. In *Proc. Comput.-Support. Coop. Work 1996*, pp. 150–59. New York: ACM Press

Moran TP, Chiu P, van Melle W. 1997. Pen-based interaction techniques for organizing material on an electronic whiteboard picking and pointing. In *Proc. User Interface Softw. Technol. 1997*, pp. 45–54. New York: ACM Press

Mosier JN, Tammaro SG. 1997. When are group scheduling tools useful? *Comput. Support. Coop. Work* 6:53–70

Muller MJ. 1991. PICTIVE: an exploration in participatory design. In *Proc. CHI 1991*, pp. 225–31. New York: ACM Press

Mynatt ED, Edwards WK, LaMarca A, Igarashi T. 1999. Flatland: new dimensions in office whiteboards: profiles, notes, and surfaces. In *Proc. CHI 1999*, pp. 346–53. New York: ACM Press

Nardi BA, Whittaker S, Bradner E. 2000. Interaction and outeraction: Instant messaging in action. In *Proc. Comput.-Support. Coop. Work 2000*, pp. 79–88. New York: ACM Press

National Research Council. 1993. *National Collaboratories: Applying Information Technology for Scientific Research*. Washington, DC: Natl. Acad. Press

Newell A, Simon HA. 1972. *Human Problem Solving*. Englewood Cliffs, NJ: Prentice Hall

Nielsen J. 1993. *Usability Engineering*. Boston, MA: Academic

Nilsen E, Jong HS, Olson JS, Biolsi K, Rueter H, Mutter S. 1993. The growth of software skill: a longitudinal look at learning and performance. In *Proc. CHI 1993*, pp. 149–56. New York: ACM Press

Nunamaker JF, Dennis AR, Valacich JS, Vogel DR, George JF. 1991. Electronic meeting systems to support group work. *Commun. ACM* 34(7):40–61

O'Hara-Devereaux M, Johansen R. 1994. *Global Work: Bridging Distance, Culture & Time*. San Francisco: Jossey-Bass

Olson GM. 1994. Situated cognition. In *Encyclopedia of Intelligence*, ed. RE Sternberg, pp. 971–73. New York: Macmillan

Olson GM, Atkins D, Clauer R, Weymouth T, Prakash A, et al. 2001. Technology to support distributed team science: the first phase of the Upper Atmospheric Research Collaboratory (UARC). In *Coordination Theory and Collaboration Technology*, ed. GM Olson, T Malone, J Smith, pp. 761–83. Hillsdale, NJ: Erlbaum

Olson GM, Moran T. 1998. Special issue: experimental comparisons of usability evaluation methods. *Hum.-Comput. Interact.* 13(3):whole issue

Olson GM, Olson JS. 2000. Distance matters. *Hum.-Comput. Interact.* 15:139–79

Olson GM, Olson JS. 2002. Groupware and computer supported cooperative work. In *Handbook of Human-Computer Interaction*, ed. JJ Jacko, A Sears. Mahwah, NJ: Erlbaum. In press

Olson JR, Olson GM. 1990. The growth of cognitive modeling in human-computer interaction since GOMS. *Hum.-Comput. Interact.* 5:221–65

Olson JS. 2001. *What's going on out there: what major companies are doing about user experience and why*. Presented at 2001 Meet. Hum. Comput. Interact. Consortium, Winter Park, CO. Univ. Michigan: CREW Tech. Rep.

Olson JS, Moran T. 1996. Mapping the method muddle: guidance in using methods for user interface design. In *Human-Computer Interface Design: Success Cases, Emerging Methods, and Real World Contexts*, ed. M Rudisill, C Lewis, PB Polson, T McKay, pp. 269–302. New York: Kaufman

Olson JS, Olson GM, Meader DK. 1995. What mix of video and audio is useful for remote real-time work? In *Proc. CHI (Comput. Hum. Interact.) 1995*, pp. 362–68. New York: ACM Press

Olson JS, Olson GM, Storrøsten M, Carter M. 1993. Group work close up: a comparison of the group design process with and without a simple group editor. *ACM Trans. Inf. Syst.* 11:321–48

Orlikowski WJ, Gash DC. 1994. Technological frames: making sense of information technology in organizations. *ACM Trans. Inf. Syst.* 12:174–207

Palen L, Grudin J. 2002. Discretionary adoption of group support software. In *Organizational Implementation of Collaboration Technology*, ed. BE Munkvold. In press

Park KS, Kapoor A, Leigh J. 2000 Lessons learned from employing multiple perspective in a collaborative virtual environment for visualizing scientific data. In *Proc. Collab. Virtual Environ. 2000*, pp. 73–82. New York: ACM Press

Pirolli P, Card SK. 1999. Information foraging. *Psychol. Rev.* 106:643–75

Prytulak L. 1971. Natural language mediation. *Cogn. Psychol.* 2:1–56

Putnam RD. 2000. *Bowling Alone: The Collapse and Revival of American Community*. New York: Simon & Schuster

Resnick P, Varian HR, eds. 1997. Special section: recommender systems. *Commun. ACM* 40(3):56–89

Rocco E. 1998. Trust breaks down in electronic contexts but can be repaired by some initial face-to-face contact. In *Proc. CHI (Comput. Hum. Interact.) 1998*, pp. 496–502. New York: ACM Press

Rocco E, Finholt T, Hofer EC, Herbsleb J. 2000. *Designing as if trust mattered*. *CREW Tech. Rep.*, Univ. Mich., Ann Arbor

Rosenfeld L, Morville P. 1998. *Information Architecture for the World Wide Web*. Sebastopol. CA: O'Reilly

Rubin J. 1994 *Handbook of Usability Testing.* New York: Wiley

Satzinger J, Olfman L. 1992. A research program to assess user perceptions of group work support. In *Proc. CHI (Comput. Hum. Interact.) 1992*, pp. 99–106. New York: ACM Press

Singhal S. 1999. *Networked Virtual Environments: Design and Implementation*. New York: Addison-Wesley

Sproull L, Kiesler S. 1991. *Connections: New Ways of Working in the Networked Organization.* Cambridge, MA: MIT Press

Stokes DE. 1997. *Pasteur's Quadrant: Basic Science and Technological Innovation*. Washington, DC: Brookings Inst. Press

Strassmann PA. 1990. *The Business Value of Computers*. New Canaan, CT: Inf. Econ. Press

Turkle S. 1995. *Life on the Screen: Identity in the Age of the Internet*. New York: Simon & Schuster

US Dep. Commerce. 2002. *A nation online: how Americans are expanding their use of the Internet*. http://www.ntia.doc.gov/ntiahome/dn/anationonline2.pdf

Veinott E, Olson JS, Olson GM, Fu X. 1999. Video helps remote work: speakers who need to negotiate common ground benefit from seeing each other. In *Proc. CHI (Comput. Hum. Interact.) 1999*, pp. 302–9. New York: ACM Press

Weiser M. 1991. The computer for the twenty-first century. *Sci. Am.* 265(3):94–104

Whittaker S, Sidner C. 1996. Email overload: exploring personal information management of email. In *Proc. CHI (Comput. Hum. Interact.) 1996*, pp. 276–83. New York: ACM Press

Winograd T. 1988. A language/action perspective on the design of cooperative work. *Hum.-Comput. Interact.* 3:3–30

Zheng J, Veinott E, Bos N, Olson JS, Olson GM. 2002. Trust without touch: jumpstarting long-distance trust with initial social activities. In *Proc. CHI (Comput. Hum. Interact.) 2002* . New York: ACM Press

Annual Review of Psychology
Volume 54, 2003

CONTENTS

Qualitative Methods

Indexes

Errata

An online log of corrections to *Annual Review of Psychology* chapters may be found at http://psych.annualreviews.org/errata.shtml