Interface Design for Health Care Environments: The Role of Cognitive Science

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An important challenge in the development of computer-based health care environments is the design of effective user interfaces. In this paper we consider a number of aspects of interface design related to the study of human-computer interaction from a cognitive perspective. It is argued that user interfaces must be designed with consideration of the information requirements, cognitive capabilities and limitations of the end users. Greater concern for fundamental research in design of user interfaces is also needed to complement short-term goals and approaches to improving user interfaces. Towards these objectives, several emerging trends are beginning to have an important impact in the design of health care interfaces. This includes the recognition of the need for iterative design and evaluation of user interfaces, applying theoretical frameworks and methods from cognitive science. An understanding of distributed as well as individual cognition will also become critical in the development of effective user interfaces as access to health care systems becomes increasingly widespread.

INTRODUCTION

The design of effective interaction between human beings and computers is a major challenge for the widespread implementation of information systems in health care. A number of issues related to both human and machine cognition, including understanding of reasoning and decision making processes, remain to be resolved. In the past, a variety of problems encountered in the design and implementation of information systems have arisen from lack of understanding of human-computer interaction and failure to consider adequately the cognitive needs of computer users [1]. In general, a focus on providing quick technological solutions to complex problems of human interaction with computers has contributed to problems encountered daily by computer users. We argue that in addition to developing short term "fixes" and solutions, fundamental research into understanding user information needs, work activities and reasoning is needed. In effect, we must understand how people think and reason about health care concepts before we make decisions about re-designing systems.

This paper provides an overview of the study of human-computer interaction in health care and suggests that an improved understanding of issues related to cognition will have an important impact for the design of user interfaces that are more intuitive and acceptable. By cognition, we mean higher level thought processes involved in comprehension, reasoning, and decision making. Cognitive science provides a unique perspective to the study of cognition, involving multidisciplinary research from areas including psychology, computer science, cognitive anthropology, philosophy and linguistics. An important area of applied cognitive science is the field of human-computer interaction (HCI).

In recent years a number of developments have occurred in the field of HCI that are beginning to profoundly affect interface design. This has included recognition of the importance of iterative evaluation (involving continual testing of user interfaces) during the design process [2], as well as the need for improved understanding of both the capabilities and limitations of the users of these systems. Concurrent developments in information technology, including networking, emergence of collaborative systems and widespread use of the World Wide Web, are already having major impact on the design and future direction of user interfaces. There is a parallel move towards development of interfaces that can support cooperative processes distributed among a number of computers and people, located across geographically separated sites. An improved understanding of human-computer interaction and the information needs of both individuals and groups (including both health care workers and patients) becomes even more important as the workplace becomes increasingly de-centralized. In this paper we present and discuss a number of issues in the design of user interfaces in health care that are related to the field of human-computer interaction, in particular, the study of human and machine cognition. The evolution of work in HCI towards a "science of design" (i.e., a research paradigm directed at understanding, furthering and disseminating design knowledge) will be considered in the context of medical informatics. Promising future directions for improving interface design will also be considered.

ADVANCES IN THE STUDY OF HUMAN-COMPUTER INTERACTION

The field of human-computer interaction has seen a number of advances in recent years. It has emerged as a highly successful area which blends fundamental study in cognitive psychology with applied work in computer science for the design and development of user interfaces. Although HCI is an evolving discipline, it has led to improvements in human interaction with computers in many domains and is having an impact in the area of medicine and health. The historical foundation of HCI was rooted in efforts during the 1970's and 1980's to develop a science of "software psychology". The goal was to establish a psychological approach to understanding software design and the use of computer systems, as well as to guide system developers in considering human factors in improving design [3]. Much of this work focused on developing general descriptions of human-computer interaction, creation of guidelines to aid system developers regarding human factors, and verification of the usability of systems. From the perspective of developing practical guidelines, a number of difficulties were encountered. For example, early attempts to develop guidelines for interface design were often based on research involving unrepresentative situations and populations (e.g., undergraduate students interacting with unrealistically simplified computer programs). Furthermore, verification of systems typically focused on assessment of completed systems (i.e., summative evaluation), making it difficult for results of evaluation to feed back into design. Much of this type of evaluation assumed the "waterfall" software life cycle, where planning of system design is conducted in a sequence of rigid and fixed stages. However, for many applications, particularly for complex and highly interactive applications, design may change dynamically and proceed in an iterative fashion, with feedback from end users leading to new ideas for design. Along these lines, the importance of design involving early and rapid prototyping and many design iterations has emerged, particularly with regard to design of user interfaces [4-5].

USABILITY ENGINEERING: DESIGN AND EVALUATION CONSIDERED TOGETHER

An important advance over the past several years, developing in parallel with work on iterative design, has been the emergence of usability engineering. Usability of a computer system can be defined as the capacity of the system to allow users to carry out their tasks safely, effectively and enjoyably [6]. In the field of medical informatics, issues of usability have come to the fore, with the ultimate acceptance or rejection of systems such as computerized patient records depending to a large extent on their usability [1]. Usability testing refers to the evaluation of information systems that involve participants (i.e., subjects) who are representative of the target user population [2]. This type of study can be used to evaluate or improve existing interfaces and to drive the design and development of new user interfaces. Usability testing directly employs a number of methods from cognitive psychology, the most important being the use of "think aloud" protocols and an emphasis on understanding the cognitive processes of computer users as they interact with user interfaces [7-8]. In applying the think aloud methods for usability testing, representative end users of health care systems (e.g. physicians or nurses) are asked to interact with the computer system and are asked to verbalize their thoughts while doing so. A number of principled methods now exist for analyzing the audiotaped recordings of subjects' thinking aloud to identify problems in the human-computer interaction, as well to describe or compare user interfaces [9].

This approach to testing user interfaces has been extended to include video recordings of subjects as they interact with user interfaces, including full recording of all interactions and computer screens [10-12]. Output from this type of testing includes the analysis of the audio and video recordings to identify usability problems (e.g., problems encountered by health care workers as they input data into computer-based patient records), as well as recommendations for changes to improve the interface (i.e., iterative feedback to designers based on identification of user problems). After changes are made to the interface, the testing cycle can begin again (e.g., with a new user population), to assess the effects of the changes. As usability testing can be conducted throughout the software life cycle (even on mock-ups of proposed screen layouts), the method is very useful in providing designers with feedback in iterative system development. Furthermore, cost-benefit analyses from a number of studies [13-14] have indicated that only a modest number of subjects are required for such testing (e.g., 8-9 subjects), but that even with only 4-5 experimental subjects, 80% of a system's usability problems can often be identified.

Research from the study of human expertise and medical cognition has provided a theoretical/methodological framework for the development and refinement of techniques that can be applied in usability testing [10]. For example, constructed descriptions of medical cases can be used as stimulus material for subjects, such as physicians, as they interact with systems (for example, subjects can be asked to enter or summarize the essential findings of the case into the computer system). This type of approach allows for experimental control in the development and presentation of information to subjects, and draws on considerable experience in the collection and analysis of such data from the study of reasoning of health care workers [15]. More recently, usability evaluations of health care technology have drawn from the study of doctor-patient interaction (involving video recording of physicians as they interview patients) and have been extended to include video recording of physicians with patients, while using a computer system in realistic situations [16].

COLLABORATION AND DISTRIBUTED COGNITION: NEW DIRECTIONS

A central issue in the cognitive study of human-computer interaction and interface design has been the development of conceptual frameworks for modelling computer users in order to identify their problems, to design more usable interfaces and generally to enhance human-computer interaction. In the past, information processing theory predominated in HCI work, where interaction was viewed as the exchange between two "information processors": the human computer user and the computer system itself. With this focus on the cognitive processing of the individual computer user, a number of influential models appeared in the literature. For example, the GOMS project [17] provided a framework for analyzing the goals, methods and actions of humans in their interaction with computers. A number of related models dealt with attempting to identify low level goals of computer users and simple computer actions such as keystrokes. However, by 1990 it became clear that such models had been ineffective in providing usable frameworks for improving system design at a broader level of understanding interaction within natural work settings [4].

In recent years a theoretical framework known as distributed cognition has emerged as an alternative perspective for considering human-computer interaction [18]. This movement, which parallels developments in cognitive psychology, goes beyond consideration of the individual and focuses on understanding cognitive activities as being distributed among a number of "agents", which can consist of human beings and machines [19]. This perspective emphasizes understanding of the design of computers and technology in the context of work places and for real tasks, which often involves collaboration. In the field of computer science this trend has also been exemplified by the creation of systems designed for collaborative applications such as video-conferencing, telecommunications and group decision support systems. With the advent of the World Wide Web, a large number of applications are being developed to support group processes and communication and co-operative interaction among many participants located at diverse sites. This has resulted in the development of two emerging disciplines, computer supported cooperative work (CSCW), concerned with developing new technologies to support work in groups, and computer-mediated communication (CMC), concerned with the psychological, sociological, and cultural aspects of computer-based collaboration [20]. The disciplines of computer science and psychology, in combination with these new emerging ones, form the basis for a multidisciplinary perspective for studying human interaction with technology [21].

Along with these developments have emerged a greater concern for social and contextual orientations in the design of human-computer interfaces, as reflected by the multi-disciplinary nature of design teams (for example, collaborating cognitive psychologists, anthropologists and sociologists [22]). In addition, "activity theory" perspectives from European research have become more prominent [23]. Activity theory spans cognitive, developmental and cultural psychology, focusing on how interactions in the world affect individual, social and cultural development [20]. In the design of medical information systems, research applying activity analysis has shown how design of an information system can enhance the interactions in medical settings as well as the larger community by supporting new tools and practices for greater patient involvement. A variety of research projects are being conducted applying methods and analyses emerging from activity theory in order to characterize the effects of information technology in clinics, hospitals and the wider patient community [21, 24-26].

As patients become increasingly involved in decisions about their own care, an improved understanding of lay reasoning and decision making will become essential for developing effective systems targeted at patient as well as health care provider populations. Our laboratory is currently applying innovative approaches to analysis of the reasoning processes of patients as they interact with educational and decision support tools. In one recent study involving analysis of diabetic patients interacting with a medical database via telecommunications technology, we found that although design of a medical information system may be in agreement with the way physicians reason, it may also be incongruent with patient conceptualizations of health and their own illness [24]. More work is needed in understanding the cognitive issues involved in providing effective interfaces for the larger population, including both patients and health care workers, in considering health care as a "team" effort.

FROM INDIVIDUAL TO DISTRIBUTED COGNITION, AND BACK AGAIN

Although it is essential to study group processes and interactions among health care workers and technology in collaborative settings, it is equally important to continue to further our understanding of the role of individuals' interaction with computers as members of collective groups. It is our contention that the information processing model and an approach to HCI which focuses on individual information processing (typically involving laboratory study) can greatly complement this emerging focus on group activity and distributed cognition. We would like to illustrate this point with an example involving design and evaluation of automated clinical patient guidelines. From our experience, we have typically started with usability testing of information systems in the experimental setting of the laboratory. This has involved having representative users interact with systems on artificial tasks, allowing us to analyze, for example, the interaction of physicians with clinical guidelines and computer-generated alerts (which in real clinical situations would only be triggered very infrequently). However, by using case scenarios (which can be designed to trigger invocation of the guidelines by the computer), we can collect extensive data on such interaction with only a few subjects. Once laboratory studies have led to changes in the design of the interface (e.g., improved look-up functions for medical terms contained in guidelines), these changes can be evaluated in the context of the natural clinical setting, using complementary but slightly modified methods (e.g., video recording of group interactions).

Along these lines, we have recently argued for an approach to human-factors engineering that allows for low-cost usability configurations and equipment to be used in laboratory settings (for video recording of computer screens) as well as for portability in taking the equipment into real settings to record "live" interaction [10]. It has been our experience that usability testing itself may need to iterate from laboratory to real world and back, depending on the questions being asked and the purposes of the analysis. Furthermore, the focus of analysis may iterate from consideration of the cognitive processes of the individual (e.g., analysis of effects of a computer-based patient record system on individual physician decision making and reasoning) and the group (e.g., analysis of the role of the computerized patient record in medical teaching rounds).

In a recent study conducted of new users of computer-based patient records, we examined the decision making of new users over time, from a baseline evaluation of their interview style with patients, to training in use of the computer system, followed by several testing sessions where subjects were requested to use the system while interviewing a "simulated patient" (an experimenter playing the role of a patient) [16]. By analyzing both the subjects' interactions with the patient and the computer-based records, it was found that over time subjects became more familiar and comfortable with the technology, and began to be guided largely by the system's sequence and organization of information in conducting patient interviews, eventually following an exclusively "screen-driven" strategy, where questions posed to patients largely matched the sequence and order of medical findings displayed on the computer screen. We are currently taking our recording equipment into the clinics to examine how such changes affect decision making in the larger context of health care (as well conducting further laboratory testing).

EVOLUTION OF USER INTERFACES

The late 1970's and early 1980's saw the development of one of the most important advances in user interface design, that of the GUI (graphical user interface). Features associated with this type of interface led to major improvements as compared to previous user interfaces, which were predominantly command-line based (e.g., UNIX and DOS user interfaces) and imposed heavy cognitive load on users to remember commands, their spelling, and procedures for using a computer system. Features that became associated with GUIs included a pointing device (typically a mouse), on-screen menus, windows that display computer activities, icons that represent files and directories, and a variety of dialogue boxes, buttons and other graphical representations. The success of these innovations, from a cognitive perspective, was based on the finding that humans attempt to understand computers as analogical extensions of familiar activities [4]. This led to a variety of user interface "metaphors" such as the "desktop" interface and "direct manipulation" interaction. With parallel developments in distributed computing and cognition (described above), embodied in trends such as the Internet, a revolution is occurring in the development of interactive user interfaces. The emerging "network-centric" user interface has been termed the "NUI" (network user interface) [27]. Design of NUIs will be influenced by the need for functions supporting collaborative cognitive processes, such as windows for telecommunication and network search functions, terminal emulators allowing the interface to be independent of particular makes of computers, consistent virtual views of resources that may be widely distributed over the Internet, and an ability to execute Web-based applications easily. Recently, there appears to be a trend in major software companies towards development of such platforms. In the area of medical informatics, the advantages of using the Web for health care applications include ease of developing interface prototypes, simplified user interface design and ability to customize the interface [28-29].

As interfaces and computer applications become tailored to such distributed environments, a number of cognitive issues come to the fore related to human ability to understand, navigate and communicate the large amount of information that is now becoming more easily accessible through networked systems [30]. In health care, rapid advances in user interfaces, hypermedia-based knowledge organization and research in visualization of data and knowledge are leading to new perspectives from which to view the representation and access of knowledge. The integration of various display modalities, including text, graphics, and other forms of multimedia, may go a long way to bring more relevant information and evidence to bear in health care. However, in order to achieve this potential, we need to understand more about the information needs and limitations of computer users, with respect to increasingly overwhelming amount of information. Using hypermedia systems, users can navigate and browse through linked networks of information nodes consisting of varied media [31]. The need for intelligent filtering of information and guidance for users of hypermedia systems has been noted by a number of authors [32-33]. Possibilities include intelligent means to alleviate information overload and to reduce the complexity of hypermedia information presented to users to more manageable and meaningful user "views". This could be extended to providing such intelligent presentation of information in ways that are tailored to the information needs and level of expertise of particular users.

ASSESSING USER NEEDS: A COGNITIVE PERSPECTIVE

In medicine, of particular relevance to creating adaptive and usable interfaces is the determination of information needs for interface design, based on study of actual use of information systems in real clinical settings. For example, Fafchamps and colleagues [34] conducted ethnographic studies of physicians' work practices, based on in situ observational methods borrowed from cultural and social anthropology. In this study, physicians were asked to "think aloud" as they examined patient charts prior to clinic. Transcripts of the physicians' thinking aloud were collected and analyzed to determine the type of questions to which physicians needed answers. It was found that much of the information that the physicians searched for was either not accessible in the paper chart or difficult to find. Based on this work, a user interface was then developed containing a patient status display that highlighted information commonly sought. Along these lines, Tuttle and colleagues [35] have recently argued that user interfaces in health care should exploit the finding from the psychological literature that humans are much better at recognizing than at recalling information from memory. Recent user interfaces to computerized patient record systems developed at the Columbia-Presbyterian Medical Center [36] and at the Mayo Clinic [11] have embodied this idea by providing physician users with context-sensitive lists of medical terms to select from when interacting with the systems to enter patient data.

Current work being conducted at our laboratory at McGill, has focused on developing and refining cognitive methods for evaluating user interfaces and assessing the information needs of diverse user populations, including both physicians and patients. Preliminary analysis of a patient clinical information system deployed on the Internet (known as PatCIS and developed at Columbia University) indicates that once systems such as clinical information repositories become accessible by not only health care workers, but also by patients, the importance of providing the appropriate level of information to individual users becomes crucial. This research extends several years work on the study of physicians' interaction with computer-based patient record systems involving physicians thinking aloud while interacting with systems in the usability laboratory, as well as analysis of doctor-patient interactions involving use of computers in natural clinical settings. Results from these studies [30] have indicated the need for user interfaces that are adaptive to the type of clinical practice as well as the level of expertise (both medical and computer related) of the users of such systems. Approaches to providing adaptability in user interfaces range from those that allow users to customize their interface based on their preferences, to systems that automatically modify their presentation of information based on contextual factors and the importance of information for particular medical situations [1]. In the area of medicine, promising work has been conducted in the development of an adaptive system (known as MIGRAINE) for providing patients with individualized information [33, 37]). The system provides information tailored to specific needs based on an individualized user model (using data derived from a patient questionnaire) as well as on the results of ethnographic studies of migraine patients.

Research on developing intelligent adaptive user interfaces that take into consideration both the context of use and the background, knowledge and understanding of the particular user is an area that will need to draw from cognitive research in user modelling [37-38]. In developing future adaptive interfaces, consideration must be given to both the system's ability to "calibrate" to the user's needs, and to the evolution of the users' knowledge and skills over time as they interact with the system.

TOWARDS A SCIENCE OF INTERFACE DESIGN

Human-computer interaction is concerned with fundamental cognitive processes involved in human interaction with technology, as well as with the applied aspects of developing better user interfaces in areas such as health care. A major focus of HCI is on understanding the processes involved in using and creating more effective and useful computer systems. As such, HCI can be considered to be a science of design [39], with a focus on understanding what we do in design and how it can be facilitated [40]. The field also seeks to codify and disseminate knowledge of design practice. As a consequence, HCI is an area where the boundary between fundamental research and applied science cannot be rigidly defined, and where there is considerable reciprocal and iterative interaction between theory and application (with HCI being both an object of research in its own right, as well as being a practical endeavor). However, HCI is not merely a haphazard interdisciplinary collaboration between the psychological sciences and engineering, but rather it has emergent properties that result from the complex interplay among human, machine, task and environment [41]. As such, HCI can be seen not just as an application area, but as a field that can motivate science at a fundamental level, by providing an empirical foundation for the iterative assessment, validation and creation of models, theories and methodologies. At one level, the area of health care provides a unique test bed for developing improved user interfaces to health care systems, and at a more general level, it can improve our understanding of processes underlying collaborative interaction and design. Not only can we conduct science in the context of practice, but by doing so we can also enrich our understanding of cognition.

In general, there are two ways in which design can be informed by work in HCI, as illustrated in Figure 1. In the top portion of the figure (fig. 1a), the direct impact that iterative feedback can have on design is indicated (using methods such as rapid prototyping in conjunction with usability testing of health care interfaces). The time frame associated with this type of feedback is relatively short, with the possibility of several iterative cycles (involving feedback from usability testing of interfaces at different stages) during the development of a user interface. At this level, changes are typically restricted to fixes for usability problems (e.g. streamlining screen design to facilitate input or search for information by users), but can also include consideration of immediate effects of interface design on higher order cognitive processes, such as reasoning and decision making.

The bottom portion of the figure (fig. 1b) illustrates a feedback cycle at a second level of abstraction, where results of design are seen as having important implications for theory development. In turn shifts in theoretical perspectives in HCI can greatly inform design, although over a longer period of time. For example, as described in this paper, one of the original HCI paradigms, that of the information processing model, led to a focus on the individual computer user (often at the fine-grained level of keystroke analysis). Over time, problems with the use of this theoretical perspective to viewing HCI led to more recent models which focus on distributed cognition and work activity. This theoretical shift has in turn influenced design of new types of user interfaces (e.g., Web-based interfaces and systems for supporting collaborative as well as individual information processing). Thus, the impact of a science of HCI can be seen at multiple levels, potentially guiding and developing more basic theoretical science, as well as leading to practical outcomes in creation of more usable interfaces. It has been our experience that work in HCI in domains such as medicine can proceed at both levels, i.e. studies conducted can lead to rapid iterative improvement of systems [10] and can also provide input into fundamental theoretical issues [30].

SUMMARY AND CONCLUSIONS

The study of human-computer interaction is beginning to have important impact in the design of user interfaces in general, as well as in application areas including health care. Over the last several decades work in this field has evolved towards more

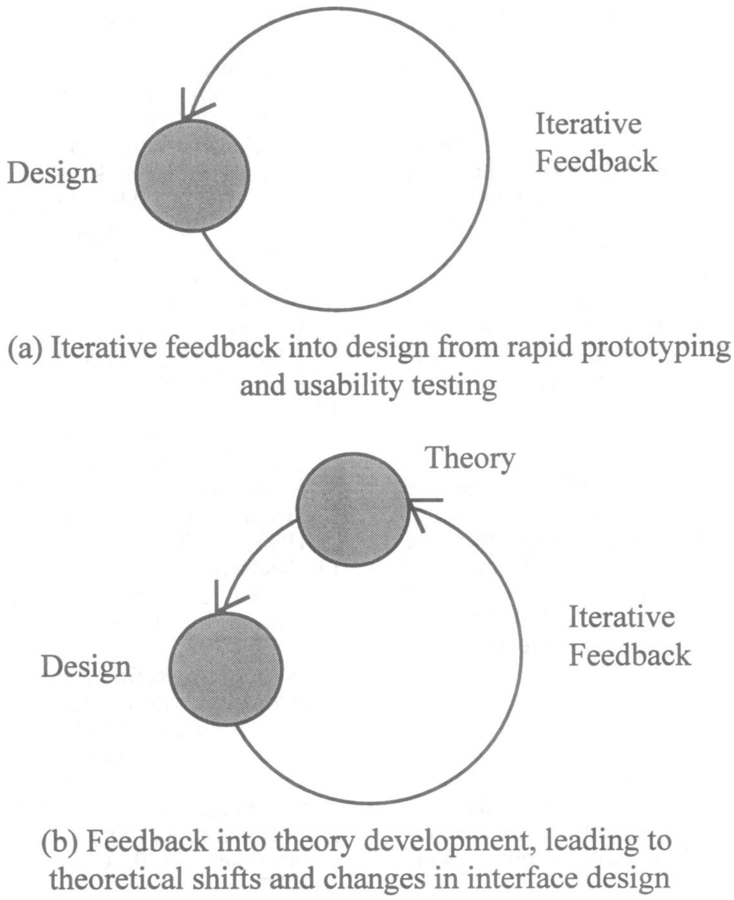

Figure 1 - Feedback in the Process of Interface Design

scientific principles and fruitful interaction between theoretical and applied objectives. Indeed, according to diSessa [42], interface design should be thought of as not merely application, but as serving a proactive role in developing and testing scientific principles. By understanding how humans are affected by their technological environments, we can develop a solid foundation for creating environments that support and enhance human cognitive capabilities.

As discussed in this paper, there are a number of advances that have emerged in recent years in the design of health care interfaces. A major shift has occurred in design methodologies, with a fixed and rigid cycle of design and development becoming increasingly replaced by iterative design, in conjunction with scientific methods of evaluation (i.e., provision of continual feedback from cognitive usability analysis of user interactions into design decisions). As a parallel trend, over the past several years there has been a movement away from exclusive focus on individuals' interaction with computer systems to a broader, more encompassing perspective based on understanding of both individual and group processes. This trend is most clearly seen in the emergence of networked systems and Internet-based approaches to providing health care. This will likely continue and will have an important impact on the nature of user interfaces in the future. In conjunction with these developments, cognitive issues will come to the fore, including a need for improved understanding of how technology can best facilitate knowledge representation and cognitive processes involved in comprehending, navigating and communicating health care knowledge.

Development of user models and adaptive user interfaces will require a better understanding of user needs and the effects of situational contexts on decision making and reasoning. Furthermore, users can be viewed as constructing meaning from interaction with computer systems, as their behaviour becomes shaped through interaction with a computer system. Greater focus will be needed on understanding this complex interplay between human and machine in the process of learning and mastering the use of new information technology. In addition, the recent move towards home care and greater involvement by patients in their own health care has important ramifications for design of user interfaces. The diversity of information needs of patients will require an improved understanding of lay reasoning and concepts of health and illness.

The design of successful user interfaces poses one of the most important challenges in the area of health care informatics. Rapid developments in technological innovation are only beginning to be matched by advances in the more recent focus on human-computer interaction. However, we need to begin by studying the world in order to develop a solid foundation for understanding cognition in health care and designing effective interfaces. Only with a scientific perspective will the full potential of technological innovation be achieved in health care.

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