Methods of Information in Medicine

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Toward a Framework for Computer-Mediated Collaborative Design in Medical Informatics

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Abstract: The development and implementation of enabling tools and methods that provide ready access to knowledge and information are among the central goals of medical informatics. The need for multi-institutional collaboration in the development of such tools and methods is increasingly being recognized. Collaboration involves communication, which typically involves individuals who work together at the same location. With the evolution of electronic modalities for communication, we seek to understand the role that such technologies can play in supporting collaboration, especially when the participants are geographically separated. Using the InterMed Collaboratory as a subject of study, we have analyzed their activities as an exercise in computer- and network-mediated collaborative design. We report on the cognitive, sociocultural, and logistical issues encountered when scientists from diverse organizations and backgrounds use communications technologies while designing and implementing shared products. Results demonstrate that it is important to match carefully the content with the mode of communication, identifying, for example, suitable uses of E-mail, conference calls, and face-to-face meetings. The special role of leaders in guiding and facilitating the group activities can also be seen, regardless of the communication setting in which the interactions occur. Most important is the proper use of technology to support the evolution of a shared vision of group goals and methods, an element that is clearly necessary before successful collaborative designs can proceed.

Keywords: Computer-Mediated Collaboration, Clinical Guidelines, Distributed Cognition, Communication Technologies, Internet-based Collaboration

1. Introduction

The accelerated development of new knowledge in medicine is providing great opportunities for improved patient care and management. At the same time, these advances increase the demands on physicians to keep up with an ever-changing knowledge base. The growth of technology and communication capabilities promises to furnish practitioners with a set of enabling tools that provide ready access to knowledge and guidelines. The development and implementation of these tools and methods are one of the central goals of medical informatics. Given the immensity of the challenge, the need for multi-institutional collaboration is increasingly being recognized [1]. This allows groups of researchers to share resources, to pool expertise, and to offer standardized programs and tools for use in multiple institutions [2].

The collaboratory notion has emerged as a cohesive aggregation of individuals and institutions that work towards a common set of objectives across disparate geographic locations. Current research collaboratories include: the Worm Community System (in which collaborators share a common database), the Upper Atmospheric Research Collaboratory (an instrument-based collaboration), and the Distributed Collaboratory Experiment Environments Program (an interactive space collaboration) [3]. One of the central goals of a collaboratory is to create a synergistic and interdependent research entity whose sum is greater than the sum of its parts. However, the very concept of a collaboratory is a rather novel one [4] and there are relatively few established paradigms for conducting computer-mediated collaborative research in informatics or in any other fields.

At present, collaboratories can be best construed as grand-scale social experiments in the development of collective intelligence. Collective intelligence is a function of individuals and groups working with a singular purpose and consisting of a seamless integration of parts, “as if the conceptual object were produced by a single good mind” [5]. There is a growing body of research that suggests that computer-mediated collaboration is a difficult enterprise, fraught with numerous cognitive, cultural, social, and technical challenges [6]. However, there is also evidence to suggest that genuine collaboration at a distance via the media of computers and wide-area networks is attainable.

How can a collaboratory achieve such a critical level of coherence? How do differing institutional goals, priorities, and cultures converge? In what ways do the decision processes differ in collaboratories? How is the division of labor effectively constituted? These are questions with which we have been grappling in our evaluation of the InterMed Collaboratory, a multifaceted Internet-based medical informatics project involving four participating institutions [7–11]. Exemplifying the goals of computer-mediated collaborative design, there are two broad mandates guiding the InterMed project. The first is principally targeted toward developing a framework that will further the development, sharing, and demonstration of numerous software and system components, data sets, procedures and tools, that in turn will facilitate and support the attainment of the collaborative application goals. The second mandate is to provide a distributed suite of clinical applications, guidelines, and knowledge bases for clinical, educational, and administrative purposes across institutions. As the different institutions have developed highly specialized knowledge bases, as well as technological expertise, the creation of such an integrated infrastructure may facilitate the delivery of quality patient care while demonstrating decreased practice variation among locales and organizations.

This article is the third in a series of papers devoted to an analysis of the processes and products of the InterMed collaboratory, drawing on methods and theories of cognitive science. The first paper provided an overview of the evaluation process and presented results concerning the coalescence of views and the effectiveness of various technologies towards accomplishing objectives [10]. Using E-mail questionnaires to understand the kinds of perceptions held by the participants, and through cognitive analysis of conference calls we found: (1) that participants agreed that the gradual development of a shared commitment to a well defined task is important for collaborative success, (2) that there was a range of views about the degree of integration of the participating institutions within the collaboratory, (3) that there was a differentiation of roles among institutions and within sites, (4) that there were preferred modes of communication for different activities, and (5) that there was a gradual evolution towards a shared conception through clarification and negotiation through conference call communications. In the second paper [12], we examined the processes involved in the generation of individual and collaborative representations of a guideline for the management of encephalopathy, using the GuideLine Interchange Format (GLIF) developed by members of the InterMed Collaboratory [11]. In this analysis, the results showed that there was an inherent variability in the representation of GLIF generated guidelines. Furthermore, we found that the completeness and effectiveness of GLIF-encoded guidelines could be improved through collaborative interaction with scientists of differing areas of expertise.

The focus of the present paper is the development of a theoretical and methodological framework for the examination of computer-mediated collaborative design and the specific benefits and challenges that arise in the use of different modalities of communication in the collaborative design process (e.g., E-mail, conference calls, and face-to-face meetings). Illustrating this framework, we analyze the processes of computer-mediated collaborative design of InterMed, and more specifically, Inter Med’s guideline-related design activities. This paper is divided into three sections. In the first, we articulate a theoretical framework for a cognitive evaluation of collaborative design. The second section presents a detailed methodological approach for analyzing this problem. In the final part of the paper, we present results from our evaluation of the InterMed Collaboratory.

1.1 InterMed: a Multi-Institutional Computer-Mediated Collaboration

InterMed began as a collaboration among the Stanford Medical Informatics (SMI) at Stanford University, the Decision Systems Group at Brigham and Women’s Hospital (BWH), and the Department of Medical Informatics at Columbia University. Researchers in the Laboratory of Computer Science at Massachusetts General Hospital (MGH), and the Centre for Medical Education at McGill University became closely involved at later dates. Individuals at each institution have rather diverse backgrounds from different medical domains and have worked in different areas of applied medical informatics. The four sites also have distinct clinical and scientific cultures that shape their work environments and influence research directions [10]. The Stanford Medical Informatics group and Brigham and Women’s Hospital’s Decision Systems Group have stronger orientations toward basic research, whereas research activities at Columbia Presbyterian Medical Center (Columbia) and Massachusetts General Hospital (MGH-Harvard) are more strongly grounded in specific applied clinical contexts. Each institution has a distinguished history in the development of tools, methods, resources, and systems.

One of the central objectives of InterMed has been to develop sets of tools and resources for disseminating clinical guidelines across medical disciplines and settings. The development of the Guideline Interchange Format (GLIF), a computer-based format that can be used to distribute guidelines across different institutions and systems has been the primary product of this undertaking [11]. The design and implementation of guidelines, however, has proven to be challenging and has led to the development of a number of different approaches that have been targeted toward a wide range of applications and populations. This generated a multitude of different models embodying different representational languages and assumptions. Each of the four InterMed sites has worked with different guideline types (e.g., screening and prevention) and formats, developing a unique local approach to the representation of clinical guidelines. Although, these points of divergence in expertise and experience are a pre-requisite for the success of a collaboratory, they present a significant obstacle for the coalescence of views and the development of a uniform approach [10].

In many respects, InterMed's design activities embody the promises as well as the challenges confronted by the domain of medical informatics. These challenges include: (1) pooling knowledge and data resources given the vastness and complexity of the domain of clinical medicine, (2) establishing uniform and standardized controlled medical vocabularies, (3) integrating and presenting various forms of media and resources, and (4) developing a canonical approach for clinical guidelines and related decision support tools [13].

InterMed has evolved a strategy for collaborative model development based on the tiered model described in InterMed's original National Library of Medicine (NLM) proposal [7] and subsequently refined with the evolution of the collaboratory. The model for development makes use of existing guideline material, which provides the stimulus to develop a generic model in a shared representation. This representation is being implemented in a newly developed representation language (GLIF) in an InterMed guideline server, which is to interface with specific local applications at different clinical sites. In this paper, we focus primarily on the shared development of GLIF so as to gain greater insight into InterMed's computer-mediated collaborative efforts.

It is useful to decompose the design objectives of the development of GLIF broadly into the following steps: (1) the selection of a set of clinical guidelines as stimulus material, (2) the development of a common guideline model, (3) the implementation of the model in a guideline server, and (4) the process of interfacing the server with local clinical applications. This staged model was based on the collaborators' initial efforts to develop a vocabulary server. Each of the four sites had been actively involved in guidelines-related research for several years and had evolved distinct models tailored to site-specific concerns and applications. In addition, each group possessed distinct philosophies concerning the nature and purpose of a shareable guideline. In fact, the initial motivation of guideline-related activity was to test and evaluate the nascent vocabulary server. In time, the focus of the collaboratory's activities shifted to developing a shared guideline model, sensitive to (and derived from) the individual guideline models previously developed at each institution.

This investigation of InterMed's computer-mediated collaborative design is based on a theoretical and methodological framework that emerges from research in the domains of design, scientific and professional collaboration, and computer-mediated communication. In the following sections, we will describe the theory developed in these domains and the main findings that are relevant to understanding InterMed's design of guideline-related products. These frameworks also provide the basis for the methodological approach as is described in Section 2.

1.2 Collaborative Design

Medical informatics can be viewed as both an applied discipline concerned with adapting and optimizing technology for the delivery of safe and effective health care, and as a basic science that addresses fundamental issues at the interfaces among computer science, information and communication science, medicine, and human behavior [14]. In this latter respect, it provides the theoretical and scientific basis for medical computing and medical information [15].

In important respects, medical informatics is part of an emerging science of design [16], which is concerned with devising artifacts to obtain specific goals. The process of design is more commonly thought of as part of an applied domain, perhaps involving the application of scientific principles, but is strongly bound by domain-specific constraints and grounded in the contexts in which an artifact is to be used. We [12] characterize medical informatics as a local science of design [17]. A local science seeks to explain aspects of a domain, rather than to derive a set of unifying principles. Unlike natural sciences, design is not reducible to fundamental principles but is guided by more abstract principles concerned with function and adaptation. In this respect, design is not merely the product of applying principles from other domains of science; it occupies a more central role in the development and testing of scientific theories. When design is conceived in this way, we can capitalize on the invariant properties of the scientific design process.

In recent years, the process of design has been the object of psychological and cognitive-science research [18, 19], both as a scientific enterprise and as an applied discipline. Within this research area, we can characterize the process of design as a problem-solving process and can apply theoretical and methodological tools to analyze and evaluate the process and products of design in terms of representations, problem spaces, and task environments. Each knowledge domain such as medicine has characteristics that impose design constraints.

1.3 Characteristics of Design Task Environments

Goel and Pirolli [19] developed the following framework for the analysis of design. It has relatively broad applicability to a range of design concerns from architecture to computer programming. Although, we feel it is a useful rubric for characterizing design, it does not sufficiently attend to matters pertaining to collaborative design. The extension of this framework to collaborative design is presented in subsequent sections.

The following are characteristics of design-task environments and their instantiations in the context of activities of the InterMed Collaboratory:

1. Distribution of information

The start state is incompletely specified, the goal state is even less specified, and the transformation function from the start to goal state is underspecified. In the context of InterMed, the start state represents a subset of the applications, knowledge, and resources previously developed at each site, and the goal state is to achieve a level of integration, to converge on a set of guideline products. Some of the transformations include developing a common syntax and semantics for a guideline format that identifies generic guideline steps and conditions.

2. Nature of constraints

Design tasks are bounded by a range of constraints, which can be specified only partially in advance. Some of the many design constraints include coverage of different guideline types (e.g., primary prevention, and screening), the need for explicit representations for computer-based implementations, and methods for specifying temporal sequences. Collaborative endeavors serve to propagate additional constraints, some of which expedite solution strategies, and others of which make them more difficult.

3. Size and complexity of problems

Design problems are generally large and complex, spanning time scales on the order of days, months or even years. Analyzing or evaluating a design process that is the magnitude of InterMed's necessitates a strategy to characterize change across several time scales, ranging from events such as the duration of a conference call, to the period covered by a monthly progress report, and to landmark dates covering months and years.

4. Component parts

Design problems have many subcomponents and decomposition is an essential element of the design problem-solving process. The multi-tiered structure of InterMed, and the division of labor distributed between and among sites, provide natural cut points for analyzing these components. For example, the overall design process included the development of a guideline server for use across institutions, creation of a common format for encoding guidelines for integration within diverse site-specific platforms (GLIF), and specifying guideline eligibility criteria within the common format.

5. Solutions

Solutions are typically not assessed in terms of right or wrong, but rather better or worse. An integral part in evaluating the process of design is to characterize heuristics for judging the effectiveness of solutions. In InterMed, for example, two separate evaluations focused on different criteria for determining the adequacy of GLIF. Focusing on the expressivity and variability of GLIF, the first evaluation found that the representation language was sufficiently expressive to be used by the site-specific applications at each of the InterMed sites [11]. However, identified sources of variability in the guideline-encoding process included the order in which the data elements were to be collected, the specification of data elements, and human error. A separate evaluation focused on the variability and completeness of GLIF encoded guidelines as they were encoded separately by several individuals [9]. In this study, variability was found to result from the expertise of the individual doing the encoding, and the computing environment in which the encoding occurred.

6. Input/output

The input to design problems consists of information about the population who will use the artifacts, the nature of the task, and the available tools and resources that can be used in the design process. In InterMed's design activities, input consists of information about the four participating institutions in which the guidelines were to be used, and the requirements of the applications at each of these sites. Resources from the individual institutions include the encoding languages such as EON (SMI) and Arden Syntax (CPMC), ongoing research at all four of the institutions on vocabulary research, and specific guidelines and protocols that had already been encoded (including AIDS protocols at Stanford and a urinary incontinence guideline at MGH?). Their output consists of artifact specification. For GLIF, this includes the details of the entry (eligibility) conditions, the data specifications, and the methods for encoding temporal information.

This cognitive perspective adapted from Goel and Pirolli enables us to determine the kinds of decisions that are made, the consideration of site-specific and generic goals, and the negotiation of these differences in the building of collaborative-design products. This cognitive analysis of the design of InterMed's guideline-related activities complements the work by Ohno-Machado and colleagues [11], who described the evolutionary process of design and the specifics of knowledge representation employed in GLIF in terms of the problems in the programming and use of GLIF.

1.4 Collaboration and Communication Modalities

The InterMed Collaboratory was formulated on an assumption that shared development activities would leverage the strengths and activities of the individual organizations while helping to assure greater generalizability and credibility of the products that would result. There was reason to accept this assumption, since investigations of the role of collaboration in scientific research [9, 20] and professional practice [21–23] have demonstrated that significant benefits accrue when scientists or practitioners work closely with others. The benefits that emerge from such studies include more explicit explanation and justification, increased efficiency, and better decision-making performance. For example, in an investigation of the processes of collaborative scientific discovery in a computer-based bio-molecular task [20], pairs of individuals working together generated more hypotheses, showed a greater degree of explication of the various alternatives in the interactive dialogue, and performed better than individuals working alone. Similarly, our investigations of collaboration in an intensive-care unit found increased efficiency through a process of "distributed cognition" [22]. In this professional setting, the tasks were divided according to domains of expertise, and to precise, but overlapping divisions of labour and responsibility. This was exemplified in the structure of communication patterns and decision-making processes.

Collaborative research and practice also demonstrate that the acquisition and use of information by a team is rather different from the process of individual data acquisition. This is reflected in the management of multiple streams of information, necessitating continuous communication and coordination among individuals leading to timely decisions. Such functioning necessitates an ability to employ and engineer the distribution of resources (e. g., knowledge and working memory) as well as the ability to communicate and off-load information (thereby dividing intellectual tasks, such as planning and decision making). A smoothly functioning research group can, in effect, function as a single cognitive entity.

One important challenge to collaborative cognition is the introduction of executive-level activities (the coordination and management of the participants), as well as task-related activities (the actual day-to-day work). For example, in a study investigating the nature and content of system-design meetings, about one fifth of the time was devoted to coordination tasks such as project and meeting management [24]. With the distribution of tasks and knowledge across participants, the manner and content of the executive activities becomes a critical aspect in maintaining the success of the collaborative effort.

A further challenge of collaboration is the need to preserve diverse individual interpretations and contributions and to coordinate these contributions. On the one hand, the challenge involves dividing a collaborative project into semi-autonomous tasks to capitalize on the distribution of work and on individual expertise. On the other hand, collaboration requires the synthesis of the respective contributions into a coherent whole [5]. This can produce tension, either by promoting individual initiative at the expense of a common collective understanding or by emphasizing coordinated activity with the concomitant risk of impeding individual progress. The patterns of communication and work activity that a group establishes are one of the key determinants of collaborative success.

All collaboration involves communication, but such communication has generally involved individuals who work together, at the same location, for some or all of the time. With the evolution of interactive modalities, ranging from early letter-writing between scientists to subsequent use of the telephone and, more recently, video-conferencing and network-based communication such as electronic mail, it has been natural to seek to understand the role that communication technologies can play in supporting collaboration, especially when the participants are geographically separated. In particular, there is a growing need to understand the effect that these modalities have in promoting and altering the collaborative design process.

Collaboration using computer technologies presents further advantages and challenges in medical research and practice. The possible advantages of using communication technologies include increased and more frequent communication, democratic dialogue with less emphasis on social hierarchical structures, and increased efficiency. Kraut et al. [25] have proposed a complementary theory to explain the effects of different modalities on collaboration. Examining collaborative writing, they found that as the equivocality or uncertainty of the task increases, there is a need for richer modalities of communication. This was particularly evident in writing tasks such as planning the structure of document. The authors also found that electronic communication was a more satisfactory medium for drafting documents, where long detailed communications can be reviewed at one's leisure, and responses can be delayed to accommodate the effort and time required.

Relevant to this discussion is an extensive meta-analysis of experimental studies between 1980 and 1990 [26] that examined the effect of electronic group-support systems (GSS) on group processes and outcomes. By contrasting users of GSS with control groups who had no access to such systems, and by measuring task strategy (e. g., depth of analysis), communication strategy and interpersonal relationships (e.g., degree of participation), they assessed the quality and timeliness of the result and the group members' satisfaction. The analysis suggests that electronic group-support systems (including systems that primarily support communication processes and some systems that support decision making) increase decision quality, the time to make decisions, and the degree of task focus (where task focus refers to depth of analysis, task-oriented communication, and the efforts to clarify task). However, the authors found that electronic group-support systems tended to decrease group consensus and member satisfaction.

A common finding in many studies is that face-to-face communication is perceived to be superior to various forms of computer-mediated communication in that it promotes trust, cooperativity, and group identity. However, this critically depends on the purpose of the communication. In complex decision making tasks, electronic groups tend to consult more, which increases the number of alternatives considered, and this may enhance the quality of decisions [26]. Electronic communications have also been shown to increase dramatically the frequency of interaction, the range of topics, and the velocity of information transmission and acknowledgement [27]. In addition, electronic communications tend to foster a more democratic dialogue whereby the effects of social status are much less pronounced than in face-to-face communication. Sproul and Kiesler [28] reported that groups that met only face-to-face were more risk averse, but when the same groups met electronically they took more risks. Introduction of prior face-to-face communication has been shown to result in significantly greater degrees of group cohesion in a laboratory-based tasks that involve computer-mediated communication. Kraut et al. [25] documented similar results in field experiments on collaborative scientific writings. Computer-mediated communication (CMC) changes the conventional rules of discourse, including coherence in the conversational thread, and frequency in turn taking, and permits asynchronous and concurrent threads [29].

Thus, these studies suggest further challenges to computer-mediated collaboration: social issues such as autonomy, trust, and sense of place [30]. The centrality of trust was supported in a series of experiments in which Kouzes found that face-to-face interaction prior to computer-mediated collaboration increased performance. Face-to-face communication offers a wide range of expressive capabilities, including gestures, facial expressions, intonation, and so forth, whereas, conventional forms of electronic communication offer a paucity of nonverbal and nontextual cues and are limited in their ability to convey emotion. Voice communication offers a subset of these capabilities, and text-based CMC, a smaller subset.

Clark and Brennan [31] present a framework in which they describe communication as a process of grounding (i. e., the development of a shared understanding of the goals of the exchange and the content of the communication) which is expected to be different for different media. Grounding is a process that involves both the act of conveying a message and an indication that the message has been understood. It is not an all-or-none process, as casual conversation between acquaintances has different criteria for efficient communication as compared to interactions between scientists working together on a research project.

In this framework, Clark and Brennan identify several constraints that apply to different media and are expected to lead to different patterns of use. These include: (1) copresence – participants share the same surroundings, (2) visibility and/or audibility – participants can see or hear each other, (3) cotemporality – communicators can convey messages synchronously; (4) reviewability – a message can be reviewed at a later time, and (5) revisability – a message can be revised before being transmitted. Not only does each medium have unique constraints on grounding, it also has associated costs such as formulation, production, reception, understanding, start-up and delay costs. Thus, for example, in email and face-to-face dialogue, the establishment of a shared understanding will take different forms. In email, people can be very explicit about the information that is being communicated, and can interact frequently without much effort. However, due to time delays, misunderstandings are more difficult to remedy. In contrast, face-to-face interaction requires that responses be given more quickly. This leads to a more interactive, and possibly less precise, exchange. The challenge is to understand how these constraints and costs are balanced across different media, and the way that technologies can affect and aid the collaboration process.

Examining InterMed within this framework, collaborative activities are enabled though synchronous or asynchronous communication media. Synchronous tools such as telephone conference calls support the simultaneous interaction of two or more group members. Asynchronous tools such as electronic mail permit users to work independently and to exchange extended communications. As we stated earlier, each medium of communication is effective for distinctively different purposes, and each one employs different grounding techniques to ensure understanding.

2. Methodological Framework

The aim of the present investigation is to examine technology-mediated collaborative design in InterMed. Using theories and methods from cognitive science, we characterize the processes and decisions made, as individuals from the four participating institutions collaborated to design guideline-related products such GLIF and the concurrent development of a CORBA based guideline server. Furthermore, to extend our understanding of the role of communication technologies in collaborative efforts, we examine the differential use of the various modalities in reaching collaborative design goals. An ancillary aim of this work is to develop a methodological framework for studying collaboration in medical informatics and beyond.

The data collected for the analysis in the InterMed collaboratory consists of observational data collected from ongoing InterMed activities and the rich repository of archival data across different communication modalities. These data are divided into two distinct time-periods that resulted in the design of GLIF: (1) the 18-month period from the inception of InterMed in May 1994 to the middle of January 1996, and (2) from the latter part of January to October, 1996. Since 1996, we have collected concurrent data from a wide variety of sources, including email communications, telephone conference calls, progress reports, audio-tapes of a two-day mini workshop, and related papers, working documents, and presentations. To capture the evolution of the InterMed Collaboratory prior to the planned data collection, however, we reconstructed the process of collaborative design from archival material, most notably email, progress reports, and other documents posted on individual web sites. Every design project has a history and this is embodied in narrative reports, individuals' memories, and in artifacts. The analysis of this history is essential to understanding the current state of affairs.

The methods adapted and used for the present analysis focus on the design activities, conceptualized as a problem solving process with ill-defined initial and goal states, and with loose constraints that shape the products of design. This design analysis includes an examination of the decisions made, the patterns of collaborative activity, the development and accomplishment of design goals, the constraints that were imposed, and the differential contribution of communication technologies.

The approach incorporates coarse, intermediate and fine-grained levels (see Table 1). The coarse analyses give broad markers of the design process, highlighting the main patterns of activity and the main activities that have occurred in the collaborative design task. The intermediate levels of analysis focus on the communication patterns, the progress of the design activities, the decisions made, and subdivision of the original goals into component parts. Fine-grained analyses consist of a more detailed examination of individual and collective contributions of the participants in negotiating shared objectives, resolving differences in perspective and distributing tasks that will contribute to the final design products. These levels of granularity allow us to explicate events over longer time spans in a more coarse fashion, as well as intensively to characterize these events. The cumulative results of these analyses reveal a fuller picture of the collaborative design process.

Table 1 Data types used for the analysis of the evolution of InterMed and the corresponding methods and levels of analyses.

InterMed data	Methods used	Level of granularity
Progress reports, email, conference calls, face-to-face	Event chronology (related to the design of guideline products)	Coarse
Progress reports	Goal analysis	Intermediate
Email	Activity analysis	Coarse
	Sociometric analysis	Intermediate
	Semantic analysis	Fine-grained
Conference calls	Analysis of design task	Intermediate
Face-to-face interaction	Analysis of design task	Intermediate
	Discourse analysis (conflict resolution and negotiation)	Fine-grained

2.1 Historical Analysis of the Design of Guideline-Related Products

In order to develop a general overview of InterMed's guideline-related activities, the first level of analysis involved charting the pivotal decisions over the entire course of the collaboratory's history. This coarse analysis assembled and synthesized multiple sources of data. The structure of the historical analysis was based on the important decisions that were identified in the progress reports. This was verified, supplemented, and elaborated by analysis of the main guideline-related activities in E-mail, conference call and transcripts of the face-to-face meetings. The preliminary analysis enables us to develop a framework for characterizing the evolution of goals, constraints on the design task, and the main decisions that led to the design of InterMed's guideline related products.

2.2 Collaborative Design and the Use of Communication Modalities

Using methods based on the work of Clark and Brennan [31], we examined the main uses of the different communication modalities in the design of GLIF and other guideline-related products. This included an identification of the frequency of use of each of these modalities, the types of activities that are predominant for each, and the patterns and evolution of collaborative activities. We interpreted these results against the grounding constraints of the modality used (such as the lack of visual input in conference calls, and the increased time for choosing one's wording in E-mail) and the context of the evolution of the collaborative design goals.

2.3 Progress Reports

The progress reports were written independently by the primary investigators at each of the four InterMed sites. These were compiled by one of the primary investigators to chart the overall progress of the collaboratory. These progress reports were then consulted in the process of determining future goals and tasks.

The progress reports from May 1994 to September of 1996 (the period of InterMed's guideline-related activities) were analyzed to identify in greater detail how the collaborative design process evolved as a loosely constrained problem solving enterprise. This intermediate level of analysis involved an analysis of the progress reports in terms of the goals, tools and strategies, constraints, and the current status in obtaining these goals. Goals were identified in relation to discussion of future activities that were planned, as well as when current work described in the progress reports was described as being a prerequisite to other tasks. Tools refer to any accomplishments or other resources (such as computer-coded guidelines and individual areas of expertise) that could contribute to the success of the design of guideline-related products. Strategies consist of any detailed plans that are laid out to coordinate the success of attaining specific goals, including the delineation of tasks, and the development of components of a goal that can be accomplished over time. Constraints, or problems, are identified as limitations in the design of the final guideline related products, such as the lack of uniformity of vocabulary used across platforms that will be using the guideline related products. Finally, current status includes those activities that were accomplished that contribute to the design of guideline related products. This allowed us to chart the design process more precisely, as they coincided with major decisions in the historical account of guideline related activities in InterMed.

2.4 E-mail and the Processes of Collaborative Design

E-mail was a frequent mode of communication used by the participants in the InterMed collaboratory, offering a fast and succinct way of making appointments, transmitting information and engaging in constructive dialogues. In order to investigate the processes of computer-mediated collaboration as it occurred in InterMed, we undertook three levels of analysis of E-mail communications. The first two center on the patterns of communication. The first analysis is largely quantitative and focuses on activity patterns. This analysis provides us with the greatest breadth of coverage. It can reveal the patterns, but not explain them, suggesting the concurrent need for more in-depth levels of analysis. Our activity analysis investigates the following three forms of activity:

1. Frequency of messages per unit time (say, 1 week)
2. Frequency of messages for each subject (as indicated in the header)

3. Subjects discussed over the course of time.

The second level of analysis, the analysis of the E-mail communication patterns at various periods of InterMed's design process, provides an intermediate level of analysis of the processes of collaborative design. These sociometric analyses enable the graphical representation of quantitative and qualitative descriptions of the email communication patterns among participants. Furthermore, we perform sociometric analyses of E-mail communications at different periods of the design process and surrounding different components of the design task. This provides us with insights about (1) who is involved in particular communications, (2) the sites involved, (3) issues that are deemed worthy of sustained attention, and (4) routine sequences of communication, including processes of negotiation for resolving conflicts that arise.

The third level of analysis is a content analysis of the email surrounding the Boston workshop. This workshop was organized to discuss GLIF, the application models at each institution, and other guideline related products. Using the same categories of the goal analysis used to analyze the progress reports, we identify how the design process, as a problem solving activity with ill-defined goals, information input and constraints can lead to the collaborative development of guideline-related products. We can also examine their relation to the overlapping yet complementary domains of expertise, shared resources and utility of discourse surrounding the design processes. Thus, the goals that are negotiated amongst different parties, the tools, strategies, constraints that affect this outcome and the decisions that are made regarding the design of the guideline related products, are examined in detail. Furthermore, the coordination and planning of the collaboratory itself in the process of the design of these products is examined through the identification of both task-related and executive activity in the E-mail exchanges.

2.5 Conference Calls

InterMed had scheduled regular conference calls to discuss the development and progress of the collaboratory, and to clarify both task-related and executive activities. The conversations during the calls are segmented into exchanges and characterized into series of statements. These included goal statements, raising issues, summarizing what has been done or previously said, as well as executive statements that pertain to the management of the conference call and the project in general. The analysis of the communication patterns and the goal analysis of InterMed conference calls during this period has been presented elsewhere [10, 24]. We use the same goal analysis to characterize guideline-related activities in conference calls, the constraints that are imposed and the negotiation of common goals through this medium, and the distribution of both task-related and executive activity.

2.6 Face-to-Face Dialogue

InterMed participants periodically met face-to-face to discuss progress and plans regarding various issues. The most significant meeting was a workshop organized in Boston on April 5th and 6th, 1996 to discuss InterMed's guideline-related projects, and more specifically GLIF – a site independent format for encoding guidelines consistent with the site-specific applications. Until this time, both E-mail and conference calls were primarily used for communicating "facts" relating to both task and executive activities, and conference calls were also used to clarify some misunderstandings. It was anticipated that the face-to-face interaction during the Boston workshop would enable the attainment of common goals across the different sites. There were real and apparent differences concerning the site-specific goals for guideline work (for example, the use of the guidelines as warning triggers or the explicit inclusion of the guidelines for clinical use). It was unclear which of these goals were to be considered in InterMed's design efforts.

The Boston meetings followed months of guideline work in which each site endeavored to communicate their views and goals regarding a common guideline representation model. Substantial planning and agenda setting predated the workshop. This was the 93rd week of the collaboratory and the previous 3 months focused InterMed efforts on guidelines. In the first 4 months of 1996, over 130 E-mails were exchanged that directly or indirectly dealt with issues to be discussed at the workshop. In addition, three conference calls were largely devoted to planning the event. In the proceeding months, these guideline representations were exchanged and discussed via E-mails and conference calls. This began to lay the foundation for a common understanding. In addition, a multi-authored paper, the result of a highly successful collaborative effort that was submitted to American Medical Informatics Association (AMIA) weeks prior to the meeting appeared to crystallize a common vision and objectives, if not the details. However, two weeks prior to the event a rather fractious conference call suggested that there were some deep philosophical differences between some of the key participants. Furthermore, there were doubts about what had been previously accomplished and what could be meaningfully achieved during the workshop. The differences had to do with the ultimate scientific and practical goals of InterMed, and whether the enterprise was or could be successful.

Since this meeting was identified as a central to the design of the GLIF, the interactions were a focus of our analysis of collaborative design. Transcripts of three small group meetings among members at the InterMed Collaboratory workshop were analyzed using methods developed by Patel, Evans and Kaufman to capture the cognitive strategies used in interaction [32], as well as intermediate and fine grained analyses complementing the use of these propositional, epistemological, linguistic pragmatics analyses with conflict analytic methods [33]. To gain a more complete understanding of the design process in face-to-face interaction, the features focused upon with the use of these methods of different level of granularity included an overview of the design related activities throughout the workshop, the relationship between the goals of the interaction and the collaborative design process and the use of argumentation strategies and evidence and the processes of negotiation in relation to the cognitive design task.

Applying these methods to develop an overview of the design activities in face-to-face interaction, the transcripts were parsed into content specific interchanges based on theories of linguistic pragmatics and categorized in terms of then subjects discussed, the problems that were identified and the decisions that were made. This analysis also included an investigation of the general nature of the interactional response to these subjects such as the repetition of past obstacles, elaboration of earlier point, and more detailed discussion of an earlier point.

More detailed analysis consisted of investigating the strategies used in collaborative problem solving activity, this included the focus of the dialogue (ensuring adequate comprehension, clarification of common goals or content specific dialogue), the nature and use of evidence and argumentation especially in circumstances where participants present with different positions, and the use of strategies such as clarification, justification and the generation of alternatives. The fine-grained analyses of the collaborative discussions were used to chart the goal changes (refinement, expansion, avoidance, or repetition), the level of detail of these discussions in relation to the development of shared knowledge and the refinement of goals, the use of negotiation strategies and the impact on the negotiation process.

3. Results

3.1 Historical Analysis of the Design of Guideline-Related Products

The chronological development of InterMed's guideline-related activities began in June of 1994, but became a central focus during the period from December 1995, to the end of October 1996. As depicted in Fig. 1, the initial products were the site-specific such as development of medical logic modules (MLMs), and the design of a relatively small guideline server. At the end of the design task, the primary guideline related product was the GuideLine Interchange Format (GLIF), which was revised and renamed as GLIF-2.

The historical analysis illustrated in Fig. 1 delineates the main events and activities of the collaborative design process from site-specific guideline products to GLIF and the guideline server. Intermediate to these products, however, the historical analysis shows that there was a need to communicate more effectively in the establishment of collaborative goals, enabling the development of a shared understanding of how the design process was to proceed, and to negotiate the individual and site-specific goals in the development of the final products. A high degree of executive activity was most predominant from February 1995 onwards. At this point, discrepancies were recognized in the understanding of the design task that could not be overcome by e-mail communication (demonstrating a constraint on the design task). In response, InterMed scheduled several site visits (face-to-face) and explored other more interactive communication technologies (such as video and telephone conferencing).

In December of 1995, it was decided that guideline-related activities should be the focus of InterMed's design efforts. This shift would enable the combination of already existing areas of expertise and guideline resources from each site, and the development of common goals critical to the success of the final guideline products. In this way, a common guideline product could be general enough to be shared by participants at each of the four institutions, and yet could satisfy site-specific needs.

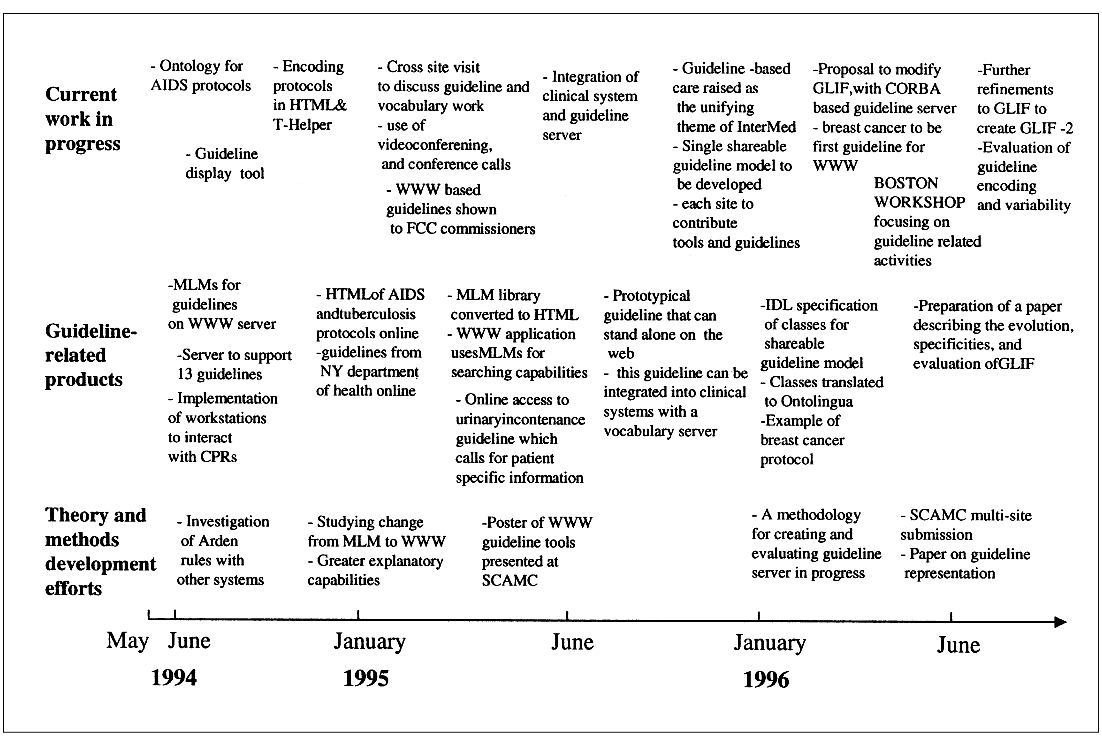

Fig. 1 Historical analysis of key events of InterMed's guideline-related work (May 1994 to September 1996).

3.2 Collaborative Design and the Use of Communication Modalities

Focusing on the differential use of communication modalities (progress reports, E-mail, conference calls, and face-to-face interaction), our analysis revealed that the frequency of use as well as the content of the exchanges differed as a function of the modality used.

While variable, E-mail was used with the greatest frequency, and gradually tended to focus on specific task-related activities. Furthermore, the content of monthly progress reports and E-mail was focused primarily on task specific activity, with discussion of the exact details of the design of the specific products (such as GLIF). The dialogue during conference calls, focused more on executive activities, such as the planning of events such as the AMIA presentation and a videoconference. Face-to-face dialogue during site visits, the Boston workshop, and conferences and presentations focused both on task-related and executive activities, enabling the specification of goals and plans in both (such as the planning of the specific details of GLIF, as well as the meeting plan for the Boston workshop itself).

The differences in use are consistent with the constraints identified by Clark and Brennan which are expected to affect the process of grounding. As predicted by the principle of least effort, the difference in the form of communication involved in E-mail and conference calls reflects the strengths and limitations of the different media [31]. With synchronous interaction, or co-temporality, the participants of conference calls during InterMed's discussion of guideline activities question at exact moments of unclarity, reassuring the speaker of understanding with non-interrupting statements throughout the conversation (such as "yes", "go on", "m", and "uhh huh"). The synchronous nature of conference calls entails that each person's contribution must be delivered quickly. If an attempt is made to wait and to more carefully formulate a contribution, this may lead to missing the groups' discussion and the perfect formulation of any one statement is not possible. Similarly, E-mail and progress reports had the advantage of reviewability and revisability, and face-to-face interaction had the advantages of co-presence, visibility and sequentiality. The efficacy of using any of these modalities for different modes of communication such as executive planning, goal refinement or content specific communication is related to these modality specific constraints.

Thus, in grounding the conversation for shared understanding, the synchronous participation of individuals during InterMed's conference calls required timely contributions and enabled participants to get quick evidence of shared understanding. During E-mail communication, on the other hand, individual contributions could be more carefully worked out. E-mail did not facilitate the clarification of misunderstandings, due to the asynchrony of the interaction. Furthermore, other cues, such as intonation, pauses and other non-explicit signals are not provided in written communication; this context must be filled in with assumptions or prior knowledge of the content and the background of the collaborator.

3.3 Progress Reports

Results from the progress reports showed that there was a gradual increase in the number of goals that were related to the guideline related projects (from three to nine), and that these goals were often developed based on earlier goals and guideline-related activities. This is illustrated in Fig. 2.

The progress reports exemplify the evolutionary process of the InterMed collaboratory as evidenced by the refinement of roles, the increasing distribution of tasks, as well as differences in the kinds of communication that occur across different media. The following trends were observed (Fig. 2):

(1) An increasing number of proposed and completed goals over time (from three goals in June 1994 to nine goals in January 1996),
(2) Building new goals based upon earlier goals (e.g. the development of a shared guideline model [Nov. 1995] based on a prototype example of an interactive guideline server [Feb. 1995] and a method for using information from the clinical system as input to the server [Oct. 1995]),
(3) A shift from site-specific goals to a combination of both site-specific and inter-site goals (e.g. from developing an ontology of AIDS clinical-trial protocols [Stanford, June 1994] to developing guideline representations more generally at all sites. At the same time by maintaining site-specific sub-goals such as translating definitions into an Ontolingua model at Columbia and writing a formal definition of the classes that should be shared in the model at Stanford [February 1996]),
(4) The refinement of goals over time leading to more specific goals or sub-goals (e.g. from the goal of developing a guideline display tool [July 1994] to deciding on an area of focus for guidelines [breast cancer, February 1996]).

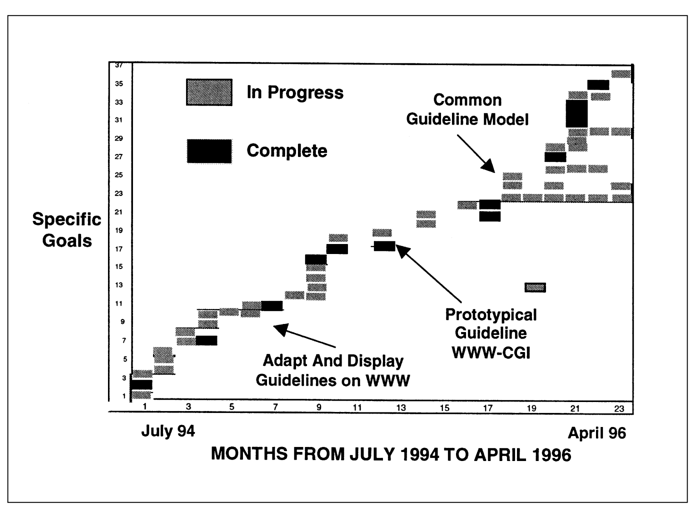

Fig. 2 Analysis of the progression of goals in InterMed as they were identified and charted through monthly progress reports.

The progress reports are indicative of greater participation from all sites over time as the collaboratory progresses, refinement and coordination of goals among sites, and the evolution of new goals based upon the development and completion of earlier goals.

Analysis of the contribution of progress reports to the collaboratory showed that written reports included primarily technical details relating to both task-related and executive activity. The participants used the progress reports to both chart their own specific activities (such as the development of a guideline server at the Columbia specific site) and relate it to the eventual InterMed goal activities (the development of a common server).

3.4 E-mail and the Processes of Collaborative Design

3.4.1 Analysis of E-mail Activity

During the period from July 1994 to April 29, 1996, we have documented 331 E-mails covering 122 topics (as determined by the subject headings on guideline research). This consists of E-mails that were sent via the various InterMed list servers to the investigators as well as E-mails from the InterMed archives. The frequency of E-mail communications per week over the course of the first 96 weeks of guideline's activity is illustrated in Fig. 3.

The inception of collaborative guideline work can be traced to the beginning of January 1995. Prior to that there was only brief mention of guidelines in emails, and reported progress was entirely site specific. This discussion emerged from an effort to develop testbed experiments for the vocabulary server. There were 45 communications over a 2 to 3 week span involving nine participants. An ambitious agenda was laid out, and efforts were targeted at selecting appropriate guidelines materials. Following this period of activity observed guidelines discussion tapered off until May 1995. For the next few months (May through July), there was some discussion about guideline's server, and a decision was made to develop a common guideline representation as the primary focus of InterMed work in year 2. This period also coincided with the commencement of regularly scheduled conference calls. Over the next few months, the AMIA guidelines demo dominated InterMed's conversation.

In December 1995 and January 1996, guidelines became the focal point of InterMed activity and E-mail frequency continued to increase over the next several months. In early January, a mini workshop was proposed and a participant from Stanford suggested a detailed agenda. In this message, several goals were set out as well as different ways to engage in collaborative activity. Different InterMed groups present their models/protocols for guideline representation. During the month of February, collaborative writing efforts towards Fall AMIA submissions intensified. In March, there was an increase in participation from all of the sites and the communication was largely devoted to planning the guidelines workshop. The workshop was held in the first week of April and we observed a temporary decline in E-mail activity. This was followed by a considerable increase in communication frequency, and the discussion was centered on different guideline models.

E-mail communications were predominately characterized by task-related activity. It is the principal vehicle of communication and is a critical instrument in facilitating day-to-day work. Participants use it to exchange documents, guideline models, and representations. There is a heterarchical structure in which any member can respond to any message or query. This creates a free flow of information and ideas. The asynchronous nature of email communication allows detailed exploration of issues. However, a common under-

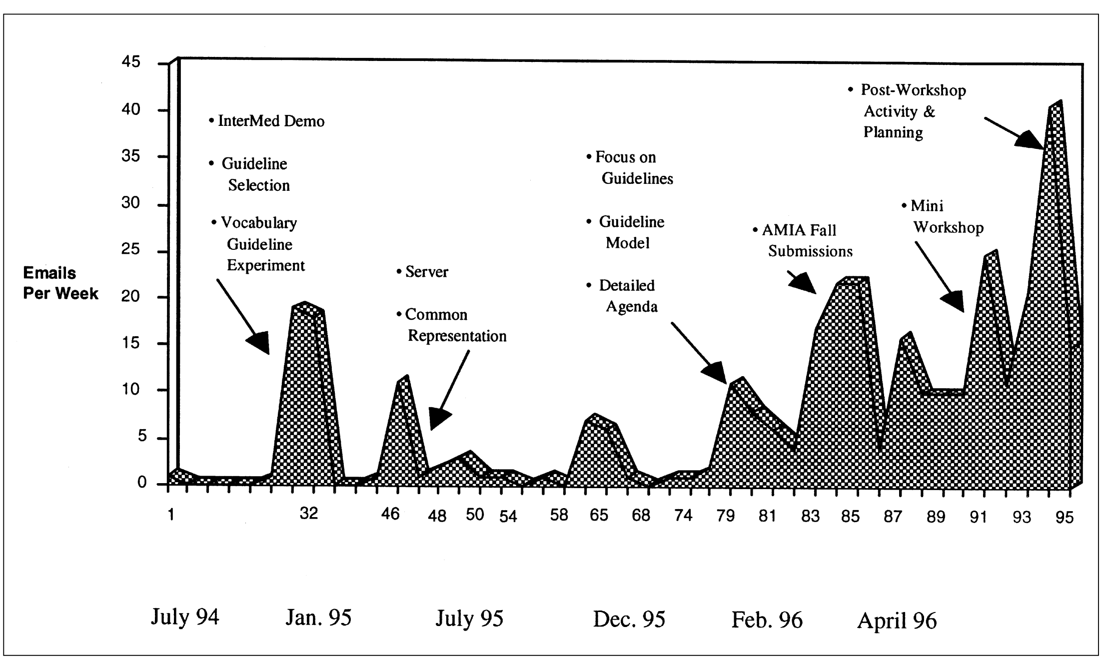

Fig. 3 Frequency of E-mail communications in InterMed per week from July 1994 to April 1996.

standing facilitates E-mail and its lack of role differentiation can present problems. We observed a couple of episodes early on in the guidelines project that were characterized by a flurry of brainstorming activity which however did not contribute to successful outcomes. The communication did not result in a clear set of objectives for further work and as a consequence, the issues were put aside for some period of time. This differed markedly from subsequent episodes (about one year later) in which objectives were clearly set forth; roles were well delineated resulting in substantial progress (e.g., completion of joint-authored papers and progress on guideline representation).

Results of our analysis of the pattern of email communication suggest an evolutionary trend in the use of email. This involved greater participation over time coinciding with the narrowing of goals and the demarcation of roles. However, the increase in participation was not continuous, with periods of increased participation interspersed with periods of minimal E-mail communication.

3.4.2 Sociometric Analysis of Communication Patterns

A sociometric analysis measuring the patterns of interaction among participants for the entire 96-week period shows that there is abundant communication among sites and between individuals. This is illustrated in Fig. 4 where each node represents a participant from one of the four principle sites and InterMed Central refers to the E-mail distribution list for the entire collaboratory. Furthermore, our results show that there is differential amount of participation by individuals at each site. Each of the primary investigators at each site has a high frequency of e-mail communication with InterMed central and other investigators (B, E, J, K), and a differential degree of participation among the other investigators at each site.

The graph indicates identifiable clusters of communication. At least one member at each of the sites corresponds with considerable frequency with specific individuals at other sites. The list is used as the principle vehicle to disseminate information. In addition, there are several cross-site dyadic patterns of communication ({BJ}, {EK}, {CK}) as well as some triads ({BJG}) which are suggestive of collaborative problem solving.

Results of the pattern of E-mail communication over time supports the increase in participation and communication between sites and individuals. Initially, the communication was limited to few participants and not very many E-mail messages as illustrated in the sociometric graph of guideline-related E-mail activity during the months of January and February, 1995 (Fig. 5). This episode was characterized by 45 exchanges between eight participants (and from three sites). At this time, there was some difficulty in reaching a consensus on the specific aim of InterMed which had been simultaneously working on many activities including creating a common vocabulary and the design of guidelines accessible via the internet. No member of the DSG group participated in this exchange. An ambitious agenda was put forth and this generated some discussion. Members contributed in different ways, for example by identifying potential clinical guideline material for the experiment. However, the episode had run its course by the middle of February, before concrete goals could be set forth. The episode was characterized by a lack of clearly differentiated roles in which the participants did not successfully complement each other. In this sense many of the tasks were not clearly delineated to individuals, and the area of focus for each individual (such as the guideline server, common guideline format, or vocabulary) was unspecified. They each made a sincere effort to contribute but did not adequately coordinate activities and distributed task responsibilities in such a way as to move forward.

Illustrating the increased involvement between sites and among individuals over time, a sociometric graph characterizing E-mail activity during the month of April 1996 is given in Fig.6. Two years after the initial E-mail exchanges concerning InterMed's guideline work, the number of participants as well as the volume of communication doubled. This four-week period included the days just prior to the workshop, a relatively quiet week during and immediately after the meeting, and a flurry of E-mail activity in the last two weeks of the month. There were 11 active participants who generated a total of 107 messages. This period was punctuated by intensive efforts to complete guideline models and represent various data sets. There was considerable focus on technical details. In general, participants seemed to have an established degree of understanding in explaining differences in representational models. This had been a source of misunderstanding prior to, and to some extent, during the workshop.

Results of the E-mail communication episodes revealed differential participation of individuals. Identified advantages of collaborative activity include the contribution of different ideas that build on those proposed by colleagues and the efficient distribution of roles and tasks among collaborators. The participants were found to contribute in an efficient and coherent way in the email exchanges. This was particularly evident when it pertained to issues such as a demo to be presented at the fall AMIA meeting, the decision to name collaboratory "InterMed" , to select a 'trademark', and the planning of a video conference. This enabled suggestions from various members to shape the direction of the discourse and to distribute the tasks for efficiency.

While the roles in the interaction surrounding particular issues were highly differentiated, our results show that the actual roles such as the initiator or leader of the conversation differed across topics. For example, while one of the researchers at DSG-Harvard was the leader of the conversation in the planning of the video conference (E), the initiator of the InterMed name and trademark was the primary investigator at Stanford (F), the demonstration was initiated by the primary investigator at MGH-Harvard (C), and the AMIA meeting was organized by the primary investigator at Columbia (A).

These results of the sociometric analysis of E-mail communication support these findings of an increase in participation from all of the sites, the differentiation of roles and the refinement of goals.

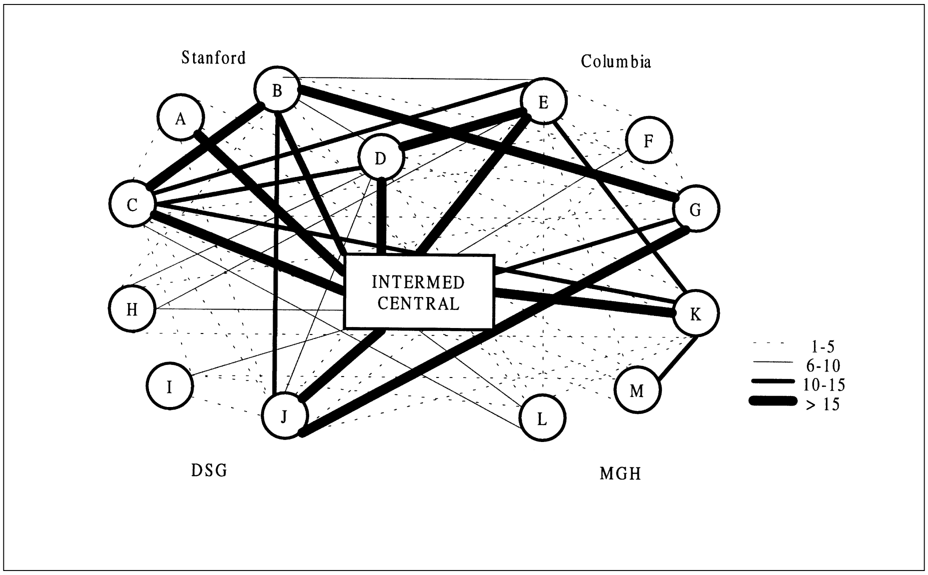

Fig. 4 Sociometric analysis of E-mail communication between individuals over the course of the 96 week analysis period surrounding the topic of guidelines.

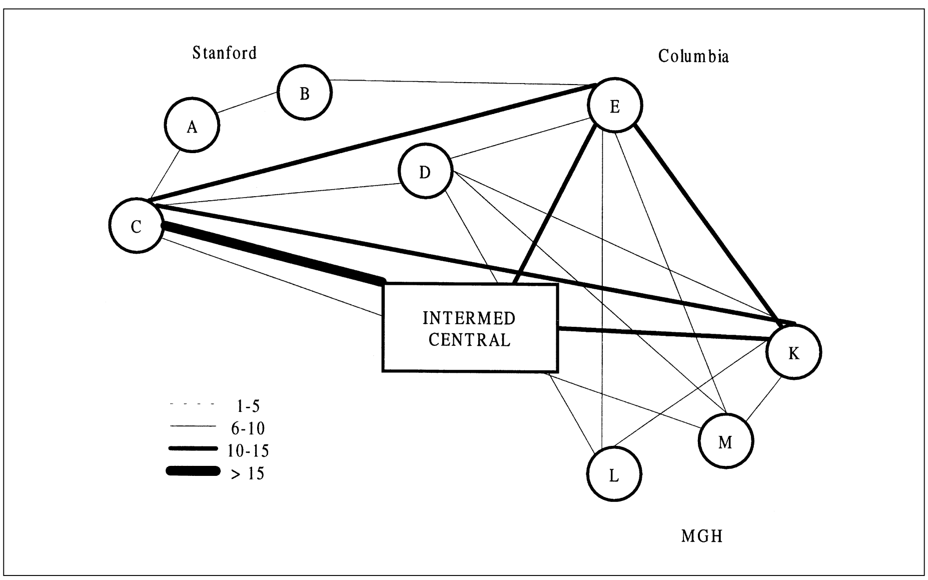

Fig. 5 Sociometric graph of E-mail communication between members of the InterMed group in January and February 1995.

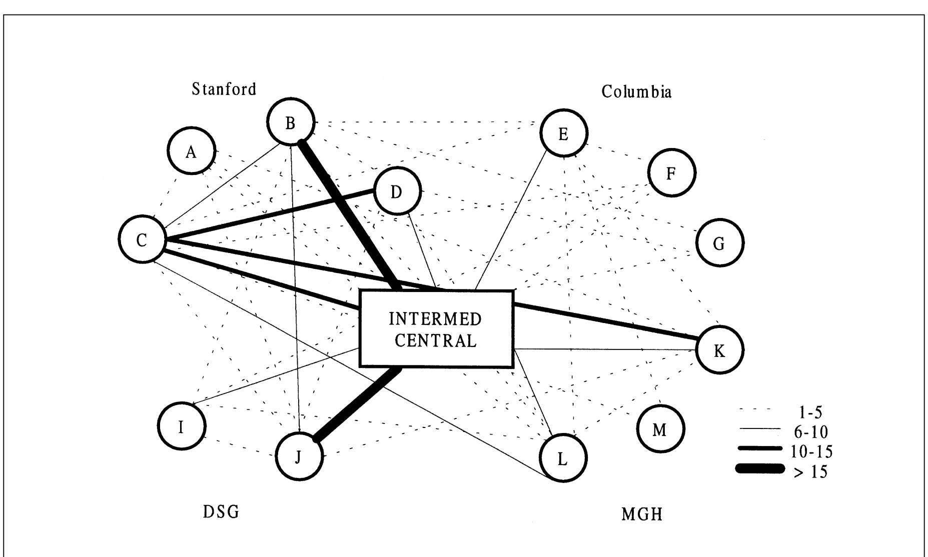

Fig. 6 Sociometric graph of E-mail communication among InterMed participants during April 1996.

3.4.3 Semantic Analysis of E-mail Content Surrounding the Boston Workshop

The E-mail communication during March and April, 1996 related information regarding over more than 50 topics, and over 150 InterMed E-mail interactions. While this was the time that required organizational coordination due to the joint authorship of a papers describing GLIF as well as the Boston Workshop, the content of E-mail communications during this time including both task-related and executive activities. Task-related included discussion of criteria representation, critical pathways, triggers for the flu vaccine, and the necessity of pre-conditions in GLIF guidelines, and the adequacy of the shared representation more generally, as well as responses to the paper, the details about site-specific applications such as EON, Arden syntax and GEODE (that are described in the paper), and the Interface Definitional Language (IDL). E-mails focusing on the executive activities were extensive during this period, especially after the face-to-face meeting on April 5th–6th. These E-mail topics included notification of an upcoming conference call, and the agenda for conference call discussion, the organization of the workshop including suggestions for the guideline workshop groups, the organization of the multi-authored paper, whether at present they should work towards an improved version (GLIF-2), and amendment procedures for the shared guideline model to ensure collaborative approval.

As the goal of organizing the workshop and the development of a shared guideline model was clarified, there was significant E-mail communication focusing on these specific goals throughout this period. However, it was during the week prior to and the three weeks following the workshop that there was an abundance of E-mail communication (11 per week vs. 25 per week averages). Furthermore, there was a general increase in the number of E-mails exchanged about most topics from the week before the workshop to the extensive task-related exchanges that occurred after the Boston workshop, leading to the increased exchange of opinions in E-mail after the face-to-face meeting.

The discussion content in E-mail reflected both the advantages and constraints imposed upon by this form of communication and the current goals of the collaborative. As the goals became more focused on guideline activities, the E-mail exchanges were more frequent than before this focus (average 2.5 E-mails per week from January 1995 to March 1996 vs. 20 E-mails per week during March and April 1996). Furthermore, due to the grounding constraints in E-mail, such as the lack of copresence, visibility and audibility, the increased task-related activity after the Boston Workshop, suggests that E-mail is more effectively used after the exchanges using richer communication modalities.

3.5 Conference Calls

Concurrent with the refinement of goals and the differential participation of individuals over time, there was a marked reduction in the number of speaking turns during the five analyzed conference calls (e.g. 452 speaking turns on February 7th decreased to 178 turns on April 24th). There was also a decrease in the number of issues that were discussed per conference call, and a decrease in the number of clarifications (steadily decreasing range from 220 to 70, mean of 121, and standard deviation of 30). These results are presented in more detail elsewhere [10].

These patterns support the evolution of the interaction and collaboration through conference calls and the unique mode of communication using this media which centered on the clarification of ambiguities in both task related and executive activities. And as in E-mail and progress reports, the content of conference calls was found to include both specific projects addressed by the collaborators (task-related activity) and the management of the collaborative (executive activity) [10, 24]. However, analysis of the conference calls between February and April 1996 demonstrates that the form of discussion was different than E-mail; whereas E-mails focused on the communication of more specific and technical facts, the conference calls focused on the negotiation and clarification of the participants' understanding of these activities [10]. For example, with significant changes in the short-term projects of InterMed, such as a shift to guideline research, and the preparation for an InterMed workshop in Boston, this was an important time in the design and clarification of the specific tasks and goals. In the process of making these changes, it was important to come to sufficient consensus for future action.

3.6 Face-to-Face Interaction

3.6.1 The Structure of Face-to-Face Interaction: Collaborative Design of GLIF

In the days preceding the meeting, the agenda and plan was set forth to outline a framework for developing a generic sharable guidelines model. Nineteen individuals participated in the meeting, including at least four representatives from each of the four sites. The participants formally met for a little more than 10 hours over the course of a day and half. The Friday morning session consisted of four presentations of site-specific guideline models and frameworks. This was followed by small group "breakout" sessions that specifically addressed a "state model" for sharable guidelines. This specific issue was arrived at after much discussion because it was judged to be most central. Following the small groups meeting, the larger group reconvened and reported on the results of their deliberations. On Saturday morning, a 3.5-hour meeting served to summarize the workshop and outline a plan for future work.

The first session involved presentations of each site's guideline model and related applications. The discourse that permeated the presentations suggested that there were still substantial gaps in understanding despite all of the prior communications and efforts. Part of the problem is that the field of medical informatics has yet to evolve crisp meanings for concepts such as eligibility criteria or state transitions (as expressed in guideline flowcharts). Much of the problem had to do with genuine differences concerning fundamental issues. These included: (1) the goals of guidelines, (2) the specifics of implementation, (3) differences as a function of medical domains (e.g., flu vaccine versus breast mass), (4) the role guidelines could play in patient encounters, (5) how they interact with electronic medical records (EMR) and more generally hospital database systems, and (6) how they can be used to facilitate physicians decisions. These differences have evolved over many years of research and development targeted towards site-specific concerns and expertise. Although, each group had previously outlined their representation model, they did not have sufficient opportunity to engage in explicit comparisons.

The morning's discussion dealt with broad issues such as how and when guidelines can be engaged in interaction with an EMR as well as very particular technical details such as particulars of a logic's syntax. As the discourse proceeded, some differences revealed themselves to be more apparent than real. The structure of the discourse ranged from extended presentation mode as a speaker outlined his model to intensive dyadic and triadic conversations. In some instances, as many as seven or eight participants contributed to an exchange. One of the more interesting exchanges took place during the first presentation (DSG1) and concerned the very important issue of eligibility criteria (Appendix 1). This resulted in 43 exchanges involving nine participants and consumed 10 minutes (25% of the time allotted for the first speaker). The discussion initially focuses on a technical matter and broadens in scope to more fundamental concerns. At this point in the discussion, broad disagreement between several of the key participants threatens to undermine the essential purpose of the representation. However, after much discussion, they reach a common understanding.

The first two sessions were partially devoted to developing a shared vocabulary, common understandings, and a precise set of objectives. In the last two sessions, it was apparent that they had made some progress working towards shared goals and the discussion focuses on more specific technical issues that are common to all issues of guideline model design. Following the last presentation of the morning, the group discussed issues that are to be the focus of the small group sessions.

The final session of the afternoon focuses on group reports. There is a discernible difference in the nature of the discourse. In important respects, they have reached a broad consensus on the issues of concern and focus on the details of the shared guideline model. The discussion is highly focused, largely substantive (as opposed to procedural), technical (rather than philosophical) and comparatively little disagreement is expressed. The following morning, the remaining participants attempted to wrap up the conference and converge on some consensus. The discussion is surprisingly wide-ranging, animated at points, with multiple simultaneous overlapping conversations. The participants make some efforts to manage and focus the discourse and the group entertains a suggestion to break into smaller ones to consider the myriad of issues left to resolve. However, the discussion proceeds in a semichaotic fashion for nearly 3.5 hours. Nevertheless, the dialogue reveals a deeper level of understanding between participants than was evident on the previous day. Despite the apparent lack of structure and coherence, they make progress delineating issues of importance and putting forth a plan to guide future activities.

The results of face-to-face interaction showed a rich and complex negotiation of goals and details in face-to-face communication. Furthermore, this negotiation process appears to have contributed to the evolutionary process of narrowing goals, distributing tasks, and accessing the different areas of expertise.

3.6.2 Negotiation in Small Group Interactions

I. The Shift From General Goals to the Negotiation of Specifics in the Process of Design

Our analysis of face-to-face interaction revealed that while there seemed to be agreement on the overall goals of GLIF after the initial presentations, the process of discussing the implementation and implications of these goals in the small group interactions led to the negotiation of more specific aspects. Initially, it appeared that there was a general agreement on the overall goals of GLIF, where differences between members consisted in only minor qualifications. However, as soon as the participants discussed how this guideline was to be used and how the particular steps and criteria were to be implemented in GLIF, there was a range of positions and opinions., Discussion of the details of the guideline model revealed that the earlier semblance of agreement was unstable. Instead, it was this discussion and resolution of these sub-goals that enabled a detailed agreement on the overall goals of GLIF.

Illustrating this shift from apparently unanimous agreement on general goals to the negotiation of several of the sub-goals is one of the small group sessions at the Boston workshop. This interaction took place between five participants, ranging from a primary investigator to a senior graduate student in medical informatics. After attending an initial presentation of all of the alternative guideline models developed at each site, the participants broke up into similar small group interactions. Each small group gathered to develop a common model that is generic enough to meet the needs of all of the institutions and remain a useful and efficient tool.

An illustrative interaction began with a discussion of the overall goal by four of the five participants. During the first five turns, the overall goal was to develop a model that can represent guidelines that are both explanatory and does not restrict the user in the clinical setting. A turn is the uninterrupted input from one of the participants. During this discussion of the overall goals of GLIF, the participants' input was restricted to the addition of qualifications (such as the need to avoid prescription), the need to make the guidelines user-friendly, and methods that can be used to develop shared representations. However, while the qualifications reveal a certain degree of difference in perspective and priorities, there is no overt disagreement to the general goal of GLIF.

During this discussion of the negotiation of a common model for GLIF, the interaction quickly proceeds to examine the details of using and developing GLIF (turn #5). It is in the discussion of these more specific goals that the negotiation process actually begins. The quick identification of issues with differing positions being held by at least two of the participants, followed by some discussion to find a solution to these discrepancies. For instance, as the conversation quickly turns to the encoding of the breast mass guideline, participant #4 introduces a concrete example of a complex case, namely the occurrence of two cysts. In response, participant #3 says that there are necessary limitations to these guidelines (implying that an attempt to address all possible contingencies is not one of the goals of the GLIF). A statement from participant #5 arbitrates the negotiation of differing positions. He says that the development of all-inclusive guidelines is not possible, as there are inherent limitations to the guidelines.

Another example of the negotiation of the sub-goals in the discussion concerns the nature of eligibility criteria into GLIF encoded guidelines. In this illustrative small group discussion, there is a series of alternatives offered to resolve the concurrent need for the completeness of a guideline, and the ability to apply these guidelines to a wide range of complex clinical circumstances. This conflict does not appear to be resolved. However, the discussion leads to the discussion of several interesting possible alternatives and warrants for their acceptance or rejection. A negotiation process, which involves the offering of alternatives, qualifications and criticisms, begins with participant #1's introduction of multiple entry points to the guideline to handle the complexity of real-world clinical cases. The criticism of this alternative is given by participant #2 as he discusses the lack of viability of such a multiple-entry approach – that is, that many of the guideline steps require input from earlier on in the guideline. Participant #3 offers a further alternative. He suggests the use of exclusionary rather than inclusionary criteria to avoid the problems of multiple entry (for example, "no breast cyst" might be exclusionary criteria). However, further discussion does not resolve the plausibility of this alternative either, as participant #5 does not see the difference between inclusionary and exclusionary criteria; both, he says, must be true for the remaining portion of the guideline. Without a unanimously supported opinion, the group does not reach a resolution regarding the eligibility criteria. However, negotiation of this specific sub-goal involves the presentation of multiple alternatives, and the discussion of reasons why these are or are not appropriate solutions. In this particular instance, the negotiation process of this sub-goal does not appear to lead to resolution.

Whereas, there appeared to be common agreement on the GLIF model when discussing it in general terms, it became clear that many of the component issues had not yet been fully worked out. Whether there was resolution or not, however, the detailed consideration of GLIF resulted in the discussion and negotiation of various alternatives and reasons that would lead to a more explicit shared understanding of GLIF.

II. Shared Knowledge and Negotiation Strategies

Results of the negotiation processes in the small group interactions revealed that the use of negotiation strategies emerged from an extensive shared knowledge base. Thus, reasons in support of the various alternatives often referred to some of the most debated issues in this field and required a certain amount of prior knowledge of the domain of medical informatics. As the disagreements arose over certain aspects of GLIF, participants often employed minimal explication of the varying positions, often giving an explicit statement why a particular alternative is not viable or by offering a similar alternative. Thus, while there was the identification and negotiation of differing positions in the small group interactions, the nature of this discourse was highly constrained by their common knowledge of the participants. This suggests a high degree of similarity that contextualized these differences. As the InterMed participants share much in common, they were able to follow the path of least negotiation.

Illustrating the role of the shared knowledge base in the negotiation process of the InterMed participants, discussion during one of the small group interactions surrounded a multiplicity of different issues. These issues included the technical details of the computer language itself, the requirements of implementing the guidelines in a clinical setting, the use of some of the terminology and issues. However, while the topics of these differences varied, the nature of the statements contributed by each of the participants depended on their common framework for the discussion to ground the negotiation. The overlap in expertise as each of the five participants each had a medical degree and had extensive experience in medical informatics grounded the discussion. The participants ranged from the head of a medical informatics center to a senior graduate student in medical informatics.

Successful negotiation emerged as a function of one or more or the following factors: compatible knowledge and experience, personality, prior beliefs, and institutional priorities. It was this overlap in the discussion of specific aspects of GLIF that enabled the constructive presentation and discussion of more minor divergences in position. Thus, the negotiation process required both some common ground and some diversity in knowledge, experience and perspective. The ability to discuss the goals and specificities of GLIF revealed that there were different understandings of the role of such a guideline and the way that these guidelines were to be instantiated.

III. The Process of Negotiation

Our results found that negotiation during face-to-face interaction involved several important processes: (1) explication and justification of the particular positions, (2) a series of alternative solutions, and (3) the refocusing of the dialogue.

– *Explication and justification of diverse goals*
  Our results show that in the process of negotiating differences, the participants of the small group interactions restricted their explications and justifications primarily to cases that in-

volved the presentation of alternatives. The negotiation in face-to-face interactions occurred as the participants closely scrutinized each of the statements made, criticized these or offered alternative suggestions. The provision of multiple alternatives, warrants and criticism for these alternatives and qualification of these positions was a highly interactive process.

- *The generation of alternatives in the design process*
  The process of negotiation often involves the presentation of several alternatives even after the establishment of the initial difference. With individuals with varying perspectives and different areas of expertise, the ability to discuss the individual positions in a small group context bring the most relevant options together to be carefully scrutinized by all of the participants. However, as argued by Okada and Simon [20], while the additional alternatives that are entertained may play a role in the improved performance of collaborative scientific discovery, the multiplication of alternatives alone is not enough to explain this difference. Rather, the negotiation process combined with accurate alternatives leads to enhanced performance.
- *Clarification of goals and examples through negotiation*
  During the process of negotiation, the dialogue often involved questioning of another participants' position by a process of refocusing: either by asking for a concrete example, or for how a particular alternative met the overall goals. This use of distributed effort was also critical to the grounding process. Each of the alternatives was examined both in terms of the compatibility that a particular instance had with the overall goal and also the particular instantiation of this goal.

4. Conclusions

Computer-mediated collaboration is playing an increasingly central role in the workplace, as well as in other spheres of life. There is little doubt that this is beginning to have profound cognitive, social, and societal consequences. The powerful affordances provided by the electronic medium of the Internet have been well documented, as have some deleterious effects that can potentially impair psychological well-being [25]. Health-care practices and doctor-patient relationships are undergoing rapid transformation. As the trend to computer-based communication accelerates we must better understand the enabling possibilities as well as the potentially adverse consequences.

The collaboratory has emerged as an innovative basis for social experiments in computer-mediated collaborative design. It serves as a means for pooling expertise to solve complex and pressing problems confronted by any scientific field. In this paper, we have articulated a multifaceted framework for characterizing and understanding the cognitive and social processes involved in computer-mediated design. The processes are revealed by changing patterns of interaction occurring over the history of a collaboratory. Our framework for considering such interactions has been developed and refined through an investigation of the InterMed Collaboratory. We used multiple methodologies and levels of analysis to provide a descriptive and explanatory characterization of the on-going design process. The framework we have developed has enabled a characterization of the kinds of decisions that were made in the design process, the constraints that were imposed, as well as the interactions and obstacles that occur as individuals with different goals, expectations and knowledge contribute to collaborative design. In order to understand fully the computer-mediated design process, we needed to use fine-grained analyses of design activities over short intervals of time (measured in hours or days), in combination with coarser levels of analyses over longer stretches of time (i.e., weeks or months).

We found that the collaborative design process involves social interactions leading to the gradual evolution and refinement of goals. This evolution is dependent on reconciling the differences in goals and knowledge among participants across institutions. For example, it was found that face to face interactions at the Boston workshop were pivotal to the coalescence of a shared view of the specific goals and design of GLIF. With email as the primary mode of communication prior to the Boston meeting, the participants recognized that the effectiveness of the endeavor was limited by the mode of interaction and the ability to resolve conflicts or misunderstandings, which required new strategies of negotiation and communication to improve the collaborative design process. The Boston meeting was thus crucial to the success of GLIF. Detailed analysis of the negotiation process during face to face encounter revealed that it was the adaptation in the face of differences in knowledge and goals that led to the clarification of ambiguities.

Our analysis of InterMed's guideline-related activities showed that the participants learned how best to use the differing communication modalities in the design process. This gradually enabled an increasingly efficient and precise use of each modality. For example, by the end of our study, the subjects clearly knew that email served to communicate specific technical details, whereas conference calls were best for clarifying executive activities, resulting in more effective and efficient communication. Face to face interaction was crucial for building trust and a shared understanding of the goals of the collaboratory. Regardless of the mode of communication, the role of leadership was found to be critical in team interaction, keeping the group focused yet giving enough freedom for the exchange of views. This executive-level functioning facilitates coordination and management of participants.

There is a growing body of empirical research documenting the various effects of computer-mediated collaboration and the conditions that lead to successful as well as sub-optimal outcomes. The emerging theoretical and methodological framework discussed in this paper has the potential to illuminate some of the underlying commonalties from other studies and to provide a basis for characterizing effective and counterproductive collaborative practices. However, we are not yet ready to propose a normative model, since each collaborative endeavor within medical informatics and in other disciplines is unique. There is clearly a need to evaluate and refine the framework in the context of other case studies. Nonetheless, we are beginning to understand some of the invariant properties of collaborative design and the effects of various enabling communication media. In its current state, the framework we have presented is strongly steeped in cognitive science and information-processing methods of analyses. This could be fruitfully extended to include a range of socio-cultural methods, including ethnographic, socio-linguistic, and activity analysis. Despite this, the promise of technology-enabled collaboration at a distance is clear and we are pleased to offer an evolving framework for the analysis and refinement of such activities, especially when design is the goal of the participants.

Appendix

1. Col 1: Why is the eligibility criterion not just the first node in the guideline? That is why... couldn't your first node simply be.... check and see if the things that you have to do to... figure out if the patient's eligible. That is if you split it as a completely separate kind of a…
2. DSG 2: Well this is really a GEODE thing, that if a patient, is in a particular state you want to find that state. You know the appropriate state for managing that patient.
3. ST 1: Well actually, you could sort them by knowledgibility criteria, and that would be useful.
4. DSG 2: Well in fact you could derive for any guideline the set of eligibility criteria for any node on that guideline by just following all the possible paths to it.
5. MGH 1: I don't think you can.
6. DSG 2: Well they're not going to be necessary, plus there might be necessary but not sufficient terms, or something.
7. MGH 1: I don't think any one of them, you first you got to start with, you know, what you're going to do different, from there you consider bi-modal mastectomies, there's a lot of things that may not be in your guideline but will be in eligibility criteria. And unless you put them there explicitly, you can't derive them.
8. DSG 2: True. No but I'm saying that if you start with, if you accept the initial eligibility criteria you could probably derive the ones for any subsequent nodes by following all paths that get to that node.
9. Col 1: Well then, you'll probably end up putting big nested list of parentheses that would be very hard to figure out. But I'm still, I'm still not satisfied. But yeah it's important, I think it's useful to index the guidelines and figure out when you'd want to run a guideline and so on, but I'm not sure that it requires a level of high level representation, but split this out and something separate that we all have to deal with, when it could be. You know to think that it would be parsimonious to simply include as.
10. DSG 1: But I think that the problem with that would be how would you know, I mean, we really are, we really want to be able to have a library of guidelines and be able to have a identify those which are applied to a patient.

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