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A study of collaboration among medical informatics research laboratories[1]

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Abstract

The InterMed Collaboratory involves five medical institutions (Stanford University, Columbia University, Brigham and Women's Hospital, Massachusetts General Hospital, and McGill University) whose mandate has been to join in the development of shared infrastructural software, tools, and system components that will facilitate and support the development of diverse, institution-specific applications. Collaboration among geographically distributed organizations with different goals and cultures provides significant challenges. One experimental question, underlying all that InterMed has set out to achieve, is whether modern

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communication technologies can effectively bridge such cultural and geographical gaps, allowing the development of shared visions and cooperative activities so that the end results are greater than any one group could have accomplished on its own. In this paper we summarize the InterMed philosophy and mission, describe our progress over 3 years of collaborative activities, and present study results regarding the nature of the evolving collaborative processes, the perceptions of the participants regarding those processes, and the role that telephone conference calls have played in furthering project goals. Both informal introspection and more formal evaluative work, in which project participants became subjects of study by our evaluation experts from McGill, helped to shift our activities from relatively unfocused to more focused efforts while allowing us to understand the facilitating roles that communications technologies could play in our activities. Our experience and study results suggest that occasional face-to-face meetings are crucial precursors to the effective use of distance communications technologies; that conference calls play an important role in both task-related activities and executive (project management) activities, especially when clarifications are required; and that collaborative productivity is highly dependent upon the gradual development of a shared commitment to a well-defined task that leverages the varying expertise of both local and distant colleagues in the creation of tools of broad utility across the participating sites.

Keywords: InterMed collaboratory; Medical informatics; Communications technologies

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> *Between collaboration and competition lies cooperation. Both collaboration and cooperation imply sharing data and other scientific resources, but the motivations and expected benefits are quite different. Cooperation may be impelled primarily out of narrow self-interest and may yield mutual benefit but not joint benefit. It can be construed as an exchange relationship… Collaboration can be construed as a communal relationship that implies social trust and synergy among participants, with mutual benefit as the result.*
>
> ([3], p. 8)

1. Introduction

The rapid proliferation of new biomedical knowledge, coupled with an increasing need to use limited resources more efficiently, has presented unique and formidable challenges to the domain of medicine. The world is also witnessing a remarkable transformation in communications technologies that is creating new opportunities for scientific exchange and access to health care information. As researchers aggressively seek new biomedical knowledge and solutions to systemic problems in the delivery of health care, it is appropriate to ask how the revolution in communications may facilitate scientific collaboration and prevent unnecessary duplication of effort.

We report here on a multi-institutional project inspired by recommendations in a 1993 report on national collaboratories from the Computer Science and Telecommunications Board of the National Research Council (NRC) [3]. The preface of that report succinctly defines the notion on which we have built our work: 'A national collaboratory is a center without walls, in which the nation's researchers can perform their research without regard to geographical location–interacting with colleagues, accessing instrumentation, sharing data and computational resources, [and] accessing information in digital libraries… [Such a collaboratory is] more than a mere interconnection of computers [and offers] a complete infrastructure of software, hardware, and networked resources to enable a full range of collaborative work among scientists' (p. vii). Our InterMed project seeks to demonstrate the viability of the collaboratory concept in the context of medical informatics research. InterMed was initiated as a collaboration among the Section on 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. Workers in the Laboratory of Computer Science at Massachusetts General Hospital (MGH), and the Centre for Medical Education at McGill University are now also closely involved[2]. The broad project goal is to use the power of the Internet to accelerate our individual progress in building site-specific applications using software and information components made available by our collaborators, to identify and construct shared infrastructure that can facilitate our local goals, to provide a broadly applicable model for such collaborative work, and to evaluate the collaboratory activities with a variety of functional, cognitive, and observational metrics.

The InterMed collaboration should be distinguished from many other collaborative groups in that we did not request (nor have we been funded) to join in the construction of any single application but rather have sought jointly to create infrastructural components that we can share among our sites in the local creation of diverse application systems. After ~ 1 year of collaborative activity, we realized that we needed to understand better the nature of our group decision making, goal setting, and development work. Experts in cognitive evaluation from McGill University accordingly joined the collaboratory as observers and evaluators, seeking to provide measures and recommendations that would provide us with formative insights into the collaborative process and thereby to help us to work together more effectively.

The geographical separation among the InterMed sites has necessitated extensive use of communications technologies to support the collaborative activities. In this report we summarize the InterMed philosophy and mission, describe our progress over three years of collaborative activities, and present study results regarding the nature of the evolving collaborative processes, the perceptions of the participants regarding those processes, and the role that telephone conference calls have played in furthering project goals. Both informal introspection and more formal observa-

[2] Due to the evolving focus of our activities, early participation in the collaboratory by the University of Utah had ended prior to the study period described in this paper.

tional work helped to shift our activities from relatively unfocused to more focused efforts while allowing us to understand the facilitating roles that communications technologies could play in our activities. The research products of the collaboration have been described elsewhere [1,4–8] and will be discussed here only in sufficient detail to provide a context for the data regarding the collaborative processes themselves.

2. Overview of the InterMed collaboratory

The emergence of advanced networking capabilities is making it feasible to consider component-based architectures that leverage the efforts of multiple participants (potentially at multiple sites), allow reuse of components, foster the emergence of standards, permit integration of services from multiple platforms, and provide a mechanism for evolution of older, more monolithic ('legacy') systems. Traditional systems for health care are primarily of a legacy nature and are poorly positioned to provide the architectural infrastructure needed for effective sharing and reuse. The InterMed collaboratory's members are similar to other investigators who are concerned about the complexity of software development, the time required to field new applications, and the failure to benefit from the experiences of others except through published articles [9]. We accordingly support ongoing efforts to develop tools and services that cater to the domain-specific needs of biomedical applications (biomedical middleware) and that facilitate the development of horizontally integrated workstation environments for medical professionals. InterMed has sought to make the construction of applications more effective by allowing developers to focus on the flow and integration of information and not on the details of the underlying components. To do this we analyzed existing applications under development at the participating sites, seeking to abstract generic needs that could cut across the various organizations. Those abstract requirements then guided us in the design and construction of shared components that could meet the diverse needs of the participating groups.

Our work has been facilitated through the use of electronic mail, file servers, World Wide Web browsers, other Internet-based applications, and conferencing tools. Fig. 1 presents schematically the communication options available to the four collaborating InterMed groups, listing also some of the attributes, applications, and areas of medical expertise that characterize and distinguish the specific institutions. As is indicated in the diagram, the McGill evaluation group has studied the use of communication facilities, as well as the evolving attitudes and goals of the participants at the four sites, each of which has a long history of medical informatics research and development. Individuals at each site have diverse backgrounds from different domains of medicine as well as in different areas of applied medical informatics. The four sites also have distinct clinical and scientific cultures that constrain their work environments and influence research directions. Stanford's Section on Medical Informatics (STANFORD) and Brigham and Women's Hospital's Decision Systems Group (BWH-HARVARD) have tended to be oriented

toward basic research, whereas research activities at Columbia Presbyterian Medical Center (COLUMBIA) and Massachusetts General Hospital (MGH-HARVARD) have tended to be more strongly grounded in specific applied clinical contexts. Our collaborative activities have been enabled through both synchronous and asynchronous communication media. Synchronous tools, such as 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.

The objectives of InterMed, as with any multi-group collaborative design process, are to further common goals as well as individual group- or site-specific goals. A high degree of integration requires a shared awareness of views, beliefs, and knowledge, despite the differing backgrounds and motivations of the participants from the various sites. However, successful collaboration also necessitates that each

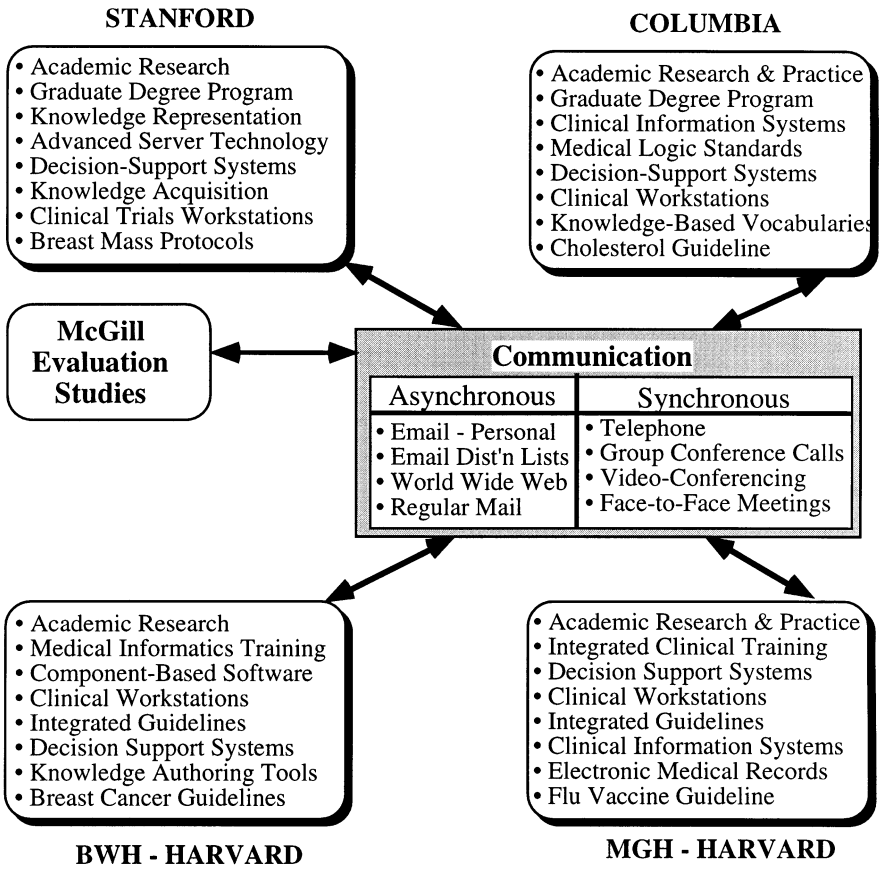

Fig. 1. Characteristics of the Research Groups in the InterMed Collaboratory and the role of the McGill Evaluation Team.

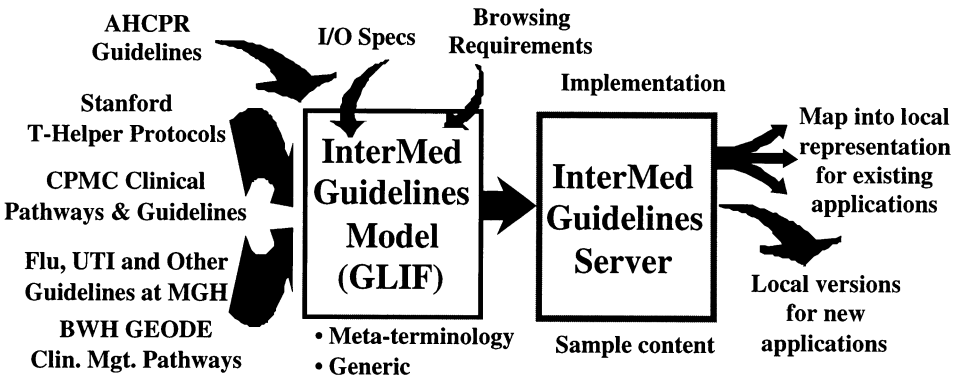

Fig. 2. InterMed Collaborative Guidelines Model Development.

group have distinct and complementary skills, domain knowledge (in our case from clinical medicine), technical expertise, and resources. The four primary institutions involved in InterMed clearly satisfy this latter criterion.

The initial work of the InterMed group had focused in part on the development of a generic vocabulary model that could be shared among the participating sites and support the needs of a wide variety of applications [6]. As we gained insight into the process by which we were evolving a shared view of a vocabulary server's role and the representation requirements, we attempted to abstract the process, defining an approach to 'collaborative model development' which we hoped would apply to other multi-institutional group development activities [10]. This initial year of work was in many respects frustrating as we began to realize that each collaborative site was highly constrained by local application-system requirements. It was difficult to focus our energies on vocabulary solutions and components that would provide well-defined capabilities of use to all participants.

With introspection, and with assistance from the McGill team as is described below, we learned how to select among subgoals and to reach a group consensus on priorities despite our varying cultures and local requirements. In particular, we began to move from the more abstract vocabulary-development work to the generation of a shared model for clinical-guideline representation and use. All InterMed sites had previously worked locally on guidelines development and on the integration of guidelines into clinical systems. Through extensive discussion, meetings, and e-mail exchanges, a shared model of clinical guidelines began to emerge (Fig. 2). As we learned about each others' approaches to guidelines representation and execution, we began to identify the common characteristics as well as methods for resolving some of the apparent central differences among the approaches. This led to the development of a shared representation for clinical guidelines which we have called the GuideLine Interchange Format (GLIF) [5]. The goal became solidified as we sought to work toward the creation of an Internet-based guideline server that would allow clinical guidelines to be downloaded and adapted for local use at each of our participating sites. It is important to emphasize, however, that

the agreement on this task had not been anticipated at the outset of our collaboration; it required an evolutionary process of discussion, feedback, and gradually improving understanding of what needs and goals best tied us to one another.

In the sections that follow, we provide pertinent background on the field of collaborative work from which our own evaluation efforts have drawn. We then describe some of the ways in which the evaluation process has contributed to our understanding of collaboration and the role of communications technologies in supporting group activities.

3. Computers, collaboration, and collaboratories

There is growing consensus that we are entering an era in which new forms of communication and collaboration will be enabled through the medium of networked computers. Such change may completely transform science, as well as other aspects of our lives. There is particular excitement about the prospects for enhancing collaborative research [11]. This has generated a sense of optimism that new collaborations will radically change the way research is done, enabling rapid progress into vexing and longstanding scientific problems. However, there is a need to temper the current rush of enthusiasm with a more realistic outlook for the challenges at hand. Enabling technologies in and of themselves do not necessarily guarantee progress. As we have learned, computer-mediated collaboration is a difficult enterprise, fraught with numerous cognitive, cultural, social, and technical challenges. However, we have come to believe that genuine collaboration at a distance via the medium of the computer is attainable.

Smith (1993) has argued that there is more to collaboration than two or more individuals jointly working on a project: 'Collaboration carries with it the expectation of a singular purpose and a seamless integration of parts, as if the conceptual object were produced by a single good mind. A requirement for collective intelligence is achieving a critical level of coherence in the work of the group' [12]. Smith proposes a theory in which a group of people can carry out a task as if the group itself were a coherent intelligent agent working with one mind rather than a collection of independent agents. The theory is built around extensions of information-processing theory to include concepts such as collective memory, strategy, processing, awareness, and control. Cooperative work, as opposed to collaboration, is viewed as less stringent in its demand for intellectual work, in that different individuals can carry out tasks satisfactorily without knowing the specifics of what others may be doing. Smith cites the human genome project as an endeavor in which the research efforts are largely cooperative rather than collaborative. Major clinical informatics efforts such as the Visible Human Project and the IAIMS Consortium might be viewed similarly. Cooperative efforts are largely equal to the sum of their parts, whereas collaborative efforts are more synergistic and interdependent.

Grosz (1996) similarly distinguishes between interaction and collaboration [13,14]. The crucial difference lies in the individuals' goals and intentions. Agents

need the intent to work in an integrative manner if they are to interleave planning and acting. Grosz points out that collaborative situations involve agents who have different beliefs and capabilities, and that partial knowledge is the rule, not the exception. Rochelle and Teasley define collaboration as 'a coordinated synchronous activity that is the result of a continued attempt to construct and maintain a shared conception of a problem' (p. 235) [15]. From our perspective, in which we have been focusing on the use of modern communication technologies, synchronous interaction is less important for some collaborative purposes (as is described below), but the construction and maintenance of a common conception is an essential component of the collaborative process.

Although collaboration requires effort and can be difficult to achieve, it is fairly commonplace and is often critical to team decision-making. Orasanu and Salas (1993) identify several important team characteristics in the context of decision making [16], including involvement of two or more individuals, multiple sources of information, interdependence and coordination among members, adaptive management of internal resources, individuals with defined roles and responsibilities, and team members possessing task-relevant knowledge. Orasanu (1990) also studied the performance of airplane pilots and flight crews trying to cope with emergency situations during simulated flight [17]. Orasanu was able to distinguish between high- and low-performing crews on the basis of their situation-assessment strategies and their communication patterns. The high performing crews gathered more relevant information, more explicitly defined problems, and planned accordingly. In addition, the captains of the superior crews more explicitly stated plans, explanations, and anticipated actions. Orasanu concluded that effective decision making is predicated on shared mental models which are built through patterns of skilled communication.

Patel, et al. (1996) have similarly characterized the process of team decision making in intensive-care medicine [18]. In this setting, multiple participants including attending staff, residents, nurses, and other personnel plan and act in a highly interactive and integrated fashion. Data are collected by different team members based on the distribution of responsibilities for information gathering, management, and processing. Each individual team member does a task-specific situation assessment, attends to any immediate problems, and then coordinates the information with the person at the next level of the hierarchy. The situation assessment involves identification and classification of the current state of the patient. The nurse is responsible for making continuous observations of the patient's condition and noting any changes in the patient's status. The nurse communicates pertinent information to the resident who will take appropriate action and then communicate with the expert clinician. The goal for each person is to work toward stabilizing, maintaining, and improving the patient's state.

The common thread in discussions of team performance is that collaboration refers to a unique process involving coordinated and integrated plans and actions, as well as shared beliefs and values among collaborators. The issue is not merely one of semantics, but it is central to the development of collaborative and communication technologies. In McGill's assessment of the InterMed collabora-

tory, the issue speaks to how one approaches the problem from a theoretical and methodological point of view. A collaborative enterprise or a collaboratory can best be viewed as a cognitive entity in which the processes of information acquisition, planning, decision-making, and learning have properties that in turn shape behaviors and determine outcomes. Grosz cites several examples from sports, science, design, and health care to support the view that interactions that fall short of genuine collaboration are not likely to lead to successful outcomes [13].

It is our contention that certain tasks necessitate genuine collaborations, whereas others may not. There is a continuum from loosely coupled cooperative efforts to highly integrated joint initiatives. In any sustained coordinated group endeavor such as InterMed, activities and tasks will fall somewhere on the continuum between highly integrated and loosely coupled.

There has been a surge of interest in studying collaboration, spurred on by the rapid developments of computer-based and communication technologies coupled with the dramatic growth of the Internet. The latter phenomenon has led to the creation of virtual communities that arise due to shared interests, visions, and goals. We have also witnessed the development of two emerging disciplines, computer supported cooperative work (CSCW) [19] and computer-mediated communication (CMC) [12]. These disciplines were created in response to the need to understand collaborative processes and to further the development of systems that facilitate communication and collaboration. CSCW is principally concerned with furthering the development of new technologies which support work in groups with different purposes, and of varying sizes, permanence, and structure. CMC researchers are more concerned with the psychological, sociological, and cultural dimensions of computer-based collaboration.

One objective of this article is to show that collaboration can be seen as a distinct psychological construct. If we can define the attributes of this construct, then we can begin to develop a theoretical framework that can answer questions about the relative success of a given collaboratory process. The framework should make distinctions between collaborative and noncollaborative processes, as well as identify factors predictive of successful outcomes. It is against this background, then, that we have sought to measure and dissect the collaborative activities that have been undertaken by workers on the InterMed project.

4. Methods and results

Influenced by past collaboration research described above, we are conducting a multi-dimensional evaluation of the InterMed collaboratory, focusing on our ongoing effort to develop a common approach to representing, encoding, and sharing clinical guidelines via a server available on the Internet [20]. The evaluation work began with electronic (e-mail) interviews performed with two or three participants from each of the InterMed sites. The interviews covered a range of issues concerning beliefs about collaboration, project objectives, priorities, expectations, and problems. As we describe below, the results of this evaluation affected

our approach to shared task definition, since we realized that our initial work had not permitted the kind of synergistic relationships that we sought to achieve in a true collaborative activity. In the months that followed, we carefully analyzed the role of telephone conference calls in supporting our growing understanding of shared goals and coordination of tasks. The analysis of conference calls, also described below, sought to determine whether the collaboratory participants were accurate in their subjective assessment of the roles that such calls play in supporting the collaboration. Separate analyses of e-mail use and face-to-face meetings are described elsewhere[3] [2,21].

5. Electronic (e-mail) interview

In early 1996, $\sim$10 months after the initiation of the InterMed project, two or three participants at each site were asked to respond to a series of e-mail interview questions posed by the McGill team. The objective was to determine points of convergence and divergence in members' beliefs, expectations, and goals. The interview consisted of a total of 21 open-ended and structured questions, devised by the McGill evaluators and addressing issues pertaining to four areas of interest: (1) collaborative processes; (2) team and task responsibility; (3) communication; and (4) priorities and progress.

Questions relating to collaborative processes solicited opinions on the meaning of collaboration and on the subjects' understanding of InterMed's activities and goals. The questions on research-team tasks and responsibilities focused on factual information about involvement in InterMed by the subject investigator and the research team. The third set of questions was intended to assess subjects' perceptions of the utilities of different asynchronous and synchronous communications media for various tasks and purposes.

The final section addressed questions pertaining to individual and site-specific priorities, and the subject's personal beliefs about the state of progress of the InterMed collaboratory.

We mailed the questions to nine participants at the different institutions and received eight responses, including three from Stanford, three from Columbia, and two from BWH-Harvard[4]. The responses ranged from rather lengthy expositions to

[3] These studies involved an analysis and characterization of the process of communication and computermediated design activities that have evolved in the InterMed collaboratory. The analysis was based on observational data collected from InterMed activities (e.g. audio-tapes of a two-day mini workshop) and a rich repository of archival data, including email communications, progress reports, and related artifacts (including all papers, working documents, presentations, proposals, and developments at each collaborator's World Wide Web site). Another analysis has involved experiments conducted at each InterMed site as team members 'thought aloud' while encoding a clinical guideline into InterMed's GLIF [8]. The objective of this evaluation work has been to gain insight into the mechanisms of the design and development process.

[4] The subject from MGH-Harvard was unable to respond due to other obligations at the time of data collection.

brief statements. In addition, some individuals did not provide answers to all of the questions. The results are summarized in the sections below.

5.1. Collaborative processes

This section consisted of four questions that solicited: (1) opinions concerning the process of collaboration; (2) the purpose of InterMed's definition (in our original funding proposal) of two tiers of activity to distinguish shared data bases and knowledge bases from the software components that use them; (3) a question that asked for comments on two polarizing statements designed to assess views of the model which best characterized the InterMed collaboratory to date; and (4) a request for comments on cross-site cultural differences. Most of the questions were open-ended and the responses are thus descriptively summarized in this paper.

The first question generated two kinds of responses: four subjects identified a typical sequence of collaborative activities, whereas the other five respondents focused more broadly on goals of the process. There was substantial convergence among the four respondents who characterized the sequence of collaborative activity, with the following processes accepted consistently across sites:

1. analysis of relevant perspectives and generation of a common goal,
2. planning activities characterized by communication (largely by e-mail) regarding emerging notions of a common model,
3. distribution of task responsibilities and activities,
4. representation and implementation of the model, plus group work on tangible products,
5. later-stage efforts to achieve synthesis.

Other responses made it clear that these processes represent a shared idealization of the collaborative model rather than a characterization of what had actually happened during the course of InterMed activities. Although the subjects appeared to understand what collaboration should be, they generally realized that it had been difficult in the initial year to reach the kinds of agreement and shared goals that were crucial for effective collaboration.

There was agreement among respondents on the purpose of the two tiers (definition of shared knowledge and data as opposed to the software components that use them). Subjects suggested that the tiers serve as a useful initial reference point, and subsequently were effective in focusing communication and research planning, although stringent adherence to the distinction between the two tiers was viewed as unnecessary as detailed work had progressed.

The third and fourth questions were open-ended, with the third asking subjects to comment on the following statements:

A. InterMed is a highly integrated collaborative endeavor with largely shared assumptions. Work on common projects requires shared efforts and a high degree of interpersonal and intergroup integration.

B. InterMed is a more loosely coupled cooperative project in which each team provides shared expertise and resources toward some common goal and also toward institution-specific goals. Progress is largely a function of individual initiative, which is later coordinated within the larger InterMed context.

Statement A represents an ideal for any collaborative endeavor. Statement B by our criteria falls well short of 'genuine collaboration'. Thus, the two statements reflect a continuum between a loosely coupled cooperative process (B) and a seamlessly integrated one (A). The statements generated an interesting range of responses as illustrated in the following quotes:

> I would say that our vision is that InterMed should be described by the first one (Stanford)

> B is much more the case. There are honest intelligent efforts at all sites to collaborate, when a focused topic emerges that people can sink their teeth into there is good response (Columbia)

> Although the first sentence is accurate, I think the second sentence understates the degree of collaboration that we are witnessing (Stanford)

> The second statement is more accurate for now (BWH)

Although each of the respondents recognized that statement A reflects a highly idealized, fully integrated model of collaboration, the five respondents from BWH-Harvard and Columbia indicated that statement B was probably a more accurate representation of the InterMed Collaboratory at the time of the interviews. The three subjects from Stanford indicated that the correct answer for InterMed lay somewhere between A and B, reflecting a somewhat more optimistic perspective on the degree of collaboration and integration that was being achieved. A similar pattern of responses emerged in response to the fourth question:

Each InterMed site is a rather distinct setting with its own local priorities, constraints, and cultures. Comment briefly on how this has (positively and adversely) affected progress in InterMed projects.

Each of the subjects responded that the differences among sites had impeded progress, but they also noted that the differences were critically important in developing a collaboratory. The three respondents from Stanford did acknowledge that the difference had been a hindrance and had taken some time to resolve, whereas the other respondents suggested that the different priorities and clashes of cultures continued to create difficulties and slow progress. One could speculate that because the Stanford group functions principally in an academic research setting, its priorities may differ from sites whose research activities are more closely affiliated with clinical service requirements. It is not uncommon for theoretical and practical perspectives on priorities to clash in the biomedical sciences as well as in other domains.

5.2. Research team, tasks and responsibilities

The second section of the questionnaire consisted of three questions pertaining to the distribution of tasks, including percent involvement of team members in InterMed projects. The schematic in Fig. 3 illustrates the roles typically played by members of the InterMed teams.

The diagram was generated partly in response to a question in which we asked participants how different members of their group contribute to InterMed-related projects. There are no sharp demarcations between roles, however, and individuals often fulfill more than one function. In addition, each site differs in important respects. The principal investigators (PIs) are involved in top-level planning, team management, and coordinating the broad objectives with the PIs at the other sites. There are also individuals at each site who coordinate tasks at a more detailed level and who orchestrate the communication process between and within groups. Conceptualizers are principally responsible for developing, refining, and coordinating guidelines and/or vocabulary models. Their activities have been most critical to InterMed's objectives. The programmers play an important role, given the currently active development objectives of InterMed, but their feedback and experience is communicated to the group as a whole, where coordinators and conceptualizers then guide the planning and redesign process. Each site has affiliated members who contribute a small percentage of their time to InterMed or related projects. The role structures are not strictly hierarchical and members may play more than one role. Stanford appears to have the clearest differentiation within the team, whereas Columbia has the least degree of demarcation, with certain individuals fulfilling multiple roles; BWH is somewhere in between the other two sites.

Much was revealed by questions regarding the percent time devoted to InterMed and related projects by various team members. There are individuals on each team, most notably the 'conceptualizers,' who devote most of their working hours to InterMed and related projects, whereas the senior team members devote $\sim 20\%$ of their time. Six of the 15 InterMed members who were referred to in the responses from subjects devote $> 50\%$ of their time to InterMed and related projects. The other contributions vary considerably. There is clearly substantial overlap between

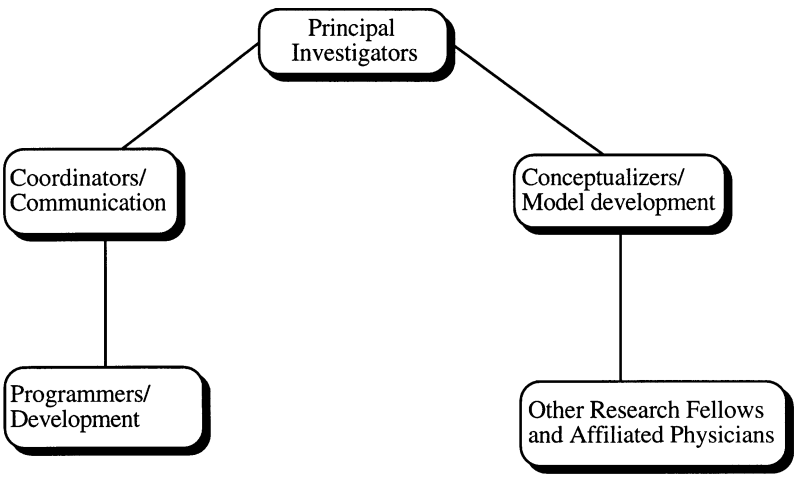

Fig. 3. Roles and responsibilities of InterMed team members.

InterMed and related projects at each institution, reflecting the degree of integration of InterMed activities within each site. This explains the difficulty in defining the explicit time commitment of participants to InterMed activities as opposed to related projects that build on InterMed infrastructure or similar technologies. Such overlap provides motivation for the work and is almost certainly a contributor to the sustenance of a collaboratory.

5.3. Communication

There were five questions that addressed factors pertaining to the utility of different methods of communication as perceived by the participants in the collaboration. One of the questions asked subjects, based on their first 18 months as members of the InterMed collaboratory, which methods of communication they found best suited for specific modes of activities such as planning, presenting, and brainstorming. The responses are summarized in Table 1.

As the Table indicates, there was substantial agreement on the forms of communication which are best suited to planning (conference calls), presentation (World-Wide Web), discussing specific technical problems (e-mail), and evaluating and critiquing proposals (e-mail). There was less convergence on which forms of communication are most useful for brainstorming and resolving conflicts. Interestingly, participants could not agree on whether synchronous or asynchronous forms were best suited for these two activities. Brainstorming is an ill-defined activity, and one in which team members often engaged spontaneously and opportunistically.

In general, responses to communication questions suggested that InterMed members had reflected upon the impact of different methods of communication on collaborative activity. They were aware of the advantages and limitations of each form of communication. Participants suggested that e-mail was most useful for detailed work and the advantages include convenience of access, and its utility in preparing documents. The limitations include the necessary effort involved in drafting a message, longer response time, and the possibility of ignoring messages. Two of the Stanford respondents indicated that conference calls and face-to-face meetings enhance e-mail communication. Review of project archives shows that the advantage of face-to-face communications was recognized as early as February 1995. In that month's progress report, the authors indicate that e-mail has serious limitations and that it is most effective when used among individual's 'who know each other well and have shared perceptions of the problems on which they are jointly working.' The questionnaire responses demonstrate a collective self-awareness, which is an attribute of a successful collaboratory [12].

5.4. Priorities and expectations

There were seven questions that addressed issues concerning priorities, expectations and progress in InterMed related projects. The questions generated a broad range of responses, although all the priorities were in keeping with the original research proposal and most had to do with vocabulary systems (a topic which was

Table 1
Forms of communication judged to be best suited for specific purposes

Subject by site	Planning	Presenting ideas	Brain-storming	Resolving conflicts	Technical discussions	Critiquing ideas of others
BWH						
A	CC	Web	FTF	FTF	EM	EM
B	CC	Web	CC	EM	EM	EM
Stanford						
C	CC	Web, FTF	EM	CC	EM	EM
D	CC, EM	FTF, Web, CC	EM	CC	EM	EM
E	CC	Web	CC	EM	FTF	EM/FTF
Columbia						
F	CC	Web	CC	CC	EM	EM
G	FTF	EM	FTF	CC	EM	EM
H	CC, EM	Web	FTF	FTF	EM	EM

CC, conference calls; WWW, World-Wide Web; FTF, face to face; and EM, e-mail.

still a major focus of attention at the time the e-mail interviews were performed). The responses are summarized in Table 2.

There is a general sense that expectations were not satisfied, due either to unrealistic goals or differences at each InterMed site. Note, however, that the responses were provided in February 1996, well before development activities for the GLIF representation language had gelled and the project's group meeting had been held in Boston (April 1996). As this study was being performed and the results analyzed, it became clear to the PIs and conceptualizers that the focus on vocabulary development had not been fruitful. It was for this reason that a major redirection of the project was undertaken, leading to the emphasis on clinical guidelines and a flurry of more focused activities that culminated in the Boston workshop. This was clearly a turning point in the project, and current (1997) perceptions of the degree of collaboration and shared vision are much more positive and uniform across the sites.

5.5. Discussion of results

In considering the degree of collaboration that had been achieved by February 1996, most respondents indicated that close collaboration reflected an ideal, whereas cooperative individual efforts were more characteristic of the current state of affairs. Several individuals noted that the level of integration had increased over the course of the project, further suggesting that true collaboration is not created de novo but, rather, grows as people work together and come to understand each others' goals and attitudes. Each of the participants emphasized that face-to-face meetings served to build trust and to promote understanding and cooperation. This is consistent with other findings in computer-mediated communication research [22]. However, InterMed is unique in the extent of its reliance on electronic communication, due to the distances among the workers, and in its focus on infrastructure development rather than the creation of single applications or products. In addition, the complexity of the domain of medicine demands a level of coherence in communication that is more substantive than in many other types of collaborative endeavors.

When asked about participants' roles, tasks, and responsibilities, the respondents indicated that there were no sharp demarcations and individuals often fulfill more than one role. The principal investigators are involved in top-level planning, team management, and coordinating the broad objectives with the PIs at the other sites. There are individuals at each site who coordinate tasks at a more detailed level and orchestrate the communication process between and within groups. Conceptualizers are principally responsible for developing, refining, and coordinating guidelines and/or vocabulary models. Their activities have been particularly critical to achieving InterMed's objectives. The programmers play an important but more peripheral role, given the currently active objectives of InterMed. It is interesting to note the substantial differences among the sites: Stanford appears to have the clearest differentiation within the team, whereas Columbia has the least degree of demarcation, with certain individuals fulfilling multiple roles; BWH appears to be some-

Table 2
Subjects' priorities, expectations, and changes observed regarding the InterMed Collaboratory

Subject by site	Priorities	Expectations	Changes
BWH			
A	Develop common vocabulary representation and server interface	Cooperative design based on collective experiences with vocabulary systems at each site	Each site has promoted their own implementation
B	Component-based software	None stated	Progress slower than anticipated
Stanford			
C	Learn how medical applications use and represent medical vocabulary. Reusable applications	Use lessons from AI and knowledge representation	Does not expect progress as planned. Domain has changed from vocabulary to the process of information in a guideline
D	None stated	Functional vocabulary server	Much learning and progress. Initial goals were unrealistic
E	None stated	Greater degree of collaboration	Multiple approaches to vocabulary. Common protocol model has emerged
Columbia			
F	None stated	Build vocabulary maintenance tools that could be used for a sharable controlled vocabulary	Vocabulary management tools have not materialized. Vocabulary needs of each group are rather different
G	Complete the next HL7 data interchange	Common applications	Common applications are not forthcoming
H	Apply theory to practice		

where between these two extremes. These distinctions are likely a function of the unique organization and culture of each institution and generally reflect the nature of their work environments (for example, an academic focus versus significant clinical responsibilities).

The differentiation of roles is analogous to distinctions among workers in other medical settings who function as a kind of layered network [18]. Each individual has a general understanding of the overall process, and is responsible for specific task components, the results of which are then communicated to other team members. Ideally, a smoothly functioning team will operate efficiently, yet maintain sufficient redundancy to avoid catastrophic errors. This kind of team effort entails both cooperation involving individual responsibility, and collaborative work involving shared responsibility.

Team members agreed substantially on the effectiveness of various modalities, such as e-mail and conference calls, for purposes such as planning, brainstorming, critiquing proposals and other collaborative activities. Conference calls were viewed as being most effective for planning and resolving conflicts, whereas e-mail was unanimously seen as the most effective modality for technical work, and critiquing proposals[5]. The World-Wide Web was believed to be an effective vehicle for preparing and sharing scientific presentations or sharing documents with images among the team members.

Questions that addressed priorities, expectations and progress generated a heterogeneous group of responses. Though all the priorities were in keeping with the original proposal, most had to do with vocabulary systems, which was an initial focus of the InterMed work. There is a general sense that expectations were not fully satisfied due either to unrealistic goals or differences among the InterMed sites. As a result, a decision was made to begin to emphasize shared modeling of clinical guidelines, which provided a more focused set of goals that met needs at all InterMed sites. This change had a dramatic effect on the group's productivity and sense of shared vision in the months that followed. All participants also recognized the synergistic effects of joint papers, presentations, and demonstrations.

6. Analysis of meeting activity during conference calls

The InterMed collaboratory has held conference calls at regular intervals (ranging from every 2 weeks to once a month). Our evaluation team recorded, transcribed, and analyzed the content of a series of conference calls between February and April of 1996 using a coding scheme developed by Olson and colleagues at the University of Michigan [11]. The scheme was developed to analyze group meetings for collaborative software design. They have extensively tested this analysis in a wide range of design meetings settings, focusing on two broad categories of activities: (1) task-related activity which focuses on the work itself, and (2) executive

[5] Detailed analysis of e-mail communications that occured among team members is provided elsewhere [21].

Table 3
Categories of activity during a conference call

Issue	The important problems, questions or aspects about the collaborative process and object design. They are often stated as 'things to be considered', problems to be addressed, and factors to be included either in the design or conception of an artifact.
Alternative	Suggested actions or course of directions to take as a means to solve a problem or shortcoming in the object design. This may include statements such 'as let us consider another approach' or 'perhaps, we should try this instead'.
Criterion	The reasons and arguments for suggesting a course of action.
Project management	Project statements of actions and tasks to be carried out by the group or by individuals, not directly related to the content of design. The statements may be of the form of 'let us decompose this problem and distribute the effort' or 'who is willing to take the lead on this'.
Meeting management	Statements or suggestions having to do with orchestrating the discussion of the meeting. Outlining topics that need to be addressed during the meeting and suggestions to continue a particular discussion by e-mail or among a few individuals after the aroun meeting.
Summary	Reviewing of the state of the design or collaborative process. May be restatement of the issues, problems about the object being designed, a review of an important e-mail, conversation or a piece of work or artiface put out before the meeting.
Walkthrough	Similar to a summary but more of a step-by-step exposition of the elements embodied in the artifact (e.g., steps in a guideline model).
Goal	Statements of what the group or individuals are trying to achieve, time constraints to accomplish certain objectives. Includes statements concerning specific tasks, as well as foundational statements about the what the collaboration may achieve. Also motivational assertions of the work being done. The category of goals directly address objectives, whereas issues and alternatives reflect broader and less concrete aims.
Clarification	A very broad category in which discussion aims to clear up misunderstandings and resolve problems. Most often a series of questions an answers, including repetitions, explanations and elaborations of particular points. Clarifications comprise many sub-divisions. There may be a clarification of any of the above categories, i.e. clarification of issue, clarification of project management. It should be noted that in any extended discussion, many of the statements can be construed as clarifications. We attempted to restrict the coding of clarifications to specific questions or responses to questions. For example, introduction of new issues would not be considered a clarification.

Table 4
Categories of activity expressed as speaking turns averaged over five conference calls

Activity category	Mean	STDEV
No. of participants	15	2.2
No. of active ($\geq$5 turns) participants	8	0.4
Speaking turns coded	208	26.7
Time (min)	41	4.9
Issue	25	8.1
Alternative	19	3.3
Goal	8	2.7
Criterion	5	0.6
Summary	2	1.1
Walkthrough	1	0.2
Project management	16	3.6
Meeting management	10	2.2
Clarifications	122	29.7

activity concerning the management of the project or the meeting itself. Table 3 describes the coding categories that were used in classifying every sentence uttered during the InterMed conference calls.

6.1. Summary analysis

The categories of activity identified for five InterMed conference calls are presented in Table 4. A 'turn' is uninterrupted speech by a single individual, and the table reflects the average number of turns in a conference call that were devoted to each of the specified categories. The data reflect calls that took place over a three month period in which there were considerable changes in the specific focus of InterMed activity. The first call took place a few weeks after guidelines research had become the focal point of InterMed work in early 1996. The final call occurred three weeks after a mini workshop that brought many project members together for face-to-face sessions in Boston. The calls lasted between and 69 min, and the number of participants ranged between ten and 13. Interestingly, the number of active participants was consistently eight or nine speakers, irrespective of the length of the calls.

The meetings were characterized by differing degrees of executive level activity (e.g., project management) and work-related activity (e.g., addressing issues). Clarifications are central to all of these telephone communications and suggest that the calls are the principal medium for generating mutual understanding. Certain activities commonly associated with software design (i.e., summaries and walk-throughs) did not play a central role in calls, reflecting either the stage of development in the various InterMed projects or the failure of conference calls to provide a suitable medium for such tasks.

The conference calls were organized by Stanford and in general Stanford had a greater number of both active and nonactive participants than other sites. In most

of the calls, 50% or more of the turns were taken by Stanford participants. The calls often had large and diverse agendas (e.g., technical issues regarding the shared server, selection of clinical guidelines to be used for experimentation, the role of peer review in selecting guidelines for use, scheduling a group workshop, submitting jointly authored papers, and concerns about security) that had been partially set up through a series of e-mail exchanges during the previous few days. Each topic received only brief discussion. Although the calls had loose agendas, they were reasonably tightly moderated by one of the principal investigators who actively directed the content of the dialogue and the exchange of turns by soliciting input from specific participants and invoking closure once the issue had been efficiently aired. The moderator would occasionally hand-off the lead for specific topics of discussion, but would then reassume control. The predominant activities were planning and brainstorming. Planning activities centered around developing and refining the guidelines research agenda. The brainstorming mode was used to chart new directions and to solicit content areas for the guidelines.

6.2. Illustrative dialogues

One conference call focused less on executive activity and more on technical details, although three of the four principal investigators were present, contributing sparingly. The discussion was dominated by InterMed members who were working on specific aspects of the guideline representation (conceptualizers), specifically the different guideline models.

The content of the discussion was very similar to that found in e-mail exchanges [2,21]. However, the form of the discussion was very different. Consider the following excerpt between an InterMed participant from Stanford and one from BWH. The discussion just prior to this excerpt focused on the purpose of a guideline model, the information needed, and its relationship to specific local applications. There was also a certain misunderstanding concerning the difference between classes and instances in a guideline model:

> BWH: But in answer to your question,… yeah, what I call the guideline model, that's directly just taken from those ideal classes.
>
> Stanford: Classes, right…
>
> BWH: Classes right.
>
> Stanford: …so what about the picture where you actually got transitions filled in with particular assertions and.
>
> BWH: Right, so those are instances of classes.

In this exchange, the two speakers have managed to ground the meaning of the basic form of BWH's guideline model. This grounding is necessary before discus-

sion can proceed to more advanced issues. The earlier misunderstanding is partially due to difference in terminologies as well as more fundamental differences in approaches embodied in BWH and Stanford guideline models.

The following discussion concerns how the guideline representation would be instantiated when using it within a local application.

Stanford: Right. But you were kind of envisioning how a local application would instantiate this guideline.

BWH: Not so much. How the guideline would be instantiated in this common representation and then a local application would, if it was running directly off of the guideline server, would download whichever of those instances are useful and run its application that way.

Stanford: Maybe I'm missing something simple but how are, since ideal instances don't, I mean since there aren't instances in IDL per se…

BWH: Right

Stanford: …how do you store permanently instance information about particular guidelines, like…

The above discussion suggests that Stanford members had different expectations about the delineated role for the guidelines server/representation and the modeling language or syntax. The BWH participant then explains how the representation/model may be translated in order to interface with clinical information. In particular, he articulates the approach used by BWH:

BWH: Sure, well what we've done here is when you translate IDL into a particular language, for instance C++…

Stanford: Right

BWH: …you end up with data structures, right? So then in instances when one of those data you have a set of data structures filled out.

Stanford: Right but that means that they're not persistent.

BWH: Oh, well that's right, but you can always… what we've done is define a relational database that allows you to store that information.

Stanford: Ah ha, that sounds interesting. Um, we would be interested in looking at that perhaps?

At this point the two discussants established a common understanding and went on to pursue the search for commonalties in the Stanford and BWH approaches. The subsequent 27 conversational turns were devoted to this issue. Interestingly, this issue was the subject of considerable discussion in previous e-mail conversations, although from the dialogue in this conference call, it was apparent that substantive differences in understanding remained. The attempt to delineate the precise role of a guideline model and/or server continued to be a source of differences in understanding.

Another conference call was supposed to be devoted to issues surrounding collaborative paper submissions for that year's SCAMC meeting (the annual Fall Symposium of the American Medical Informatics Association). The predominant mode of exchange during this call was conflict resolution. This period had been punctuated by frequent e-mail exchanges on this matter and by considerable progress, which ultimately resulted in successful outcomes (as determined by InterMed submissions and acceptances, and the level of integration on one paper in particular which was jointly authored by participants from all sites). The first part of this conference call did address details concerning the submissions and related guideline points of convergence, and especially points of divergence. In particular, the discussions dealt with specific differences in the Stanford and BWH approaches to modeling. Then a Stanford discussant made reference to an e-mail discussion that had recently ensued among several senior investigators. That discussion dealt with the broad objectives, goals and basic philosophies that are at the core of InterMed activities. This issue is illustrated in the following excerpt:

> MGH: Yeah, basically I got concerned because... I couldn't figure out what they were trying to do. I really was trying to find some sort of concept of the objective. And what we would do, in any way that would seem to be useful to the rest of the world.
>
> Stanford: Ah, but that's where I haven't really commented yet in response to that. Maybe we can get this dialogue going a little bit now, and let others participate because it seems sort of related to just the conversation that others were just having as well. It really has to do with what the fundamental nature of this endeavor is. I view this as a scientific enterprise, in which we are trying to derive some basic principles and insights from a lot of very specific and applied activities of each of our sites. And ultimately the nature of science in our field is to do that kind of thing. The goal being that if we really get at a firm conceptual understanding, that allows us to define a representation and a perspective on guidelines that is compatible with what each of us with our own local needs has defined, that we will have made a contribution to the field that goes well beyond what that specific shared representation does for any one of us. That shared representation helps define what others should be doing at our own institutions and elsewhere in the future…

> MGH: Well I think part of my problem was that it seemed that 90% of the effort was spent on the theoretical underpinnings without really examining a sufficient number of real, honest-to-goodness guidelines and real, honest-to-goodness applications to see what the problem was.

This discussion continued for a few more minutes before attention was turned towards modeling issues to be addressed during the workshop. The competing goals of theoretical science and applied development are part of the fabric of InterMed, and more generally, medical informatics as a discipline. Progress is to some degree contingent on the convergence of different visions of InterMed's ultimate objectives.

6.3. Discussion of results

In examining the content of the conference calls, one can identify two broad categories of activities: task-related activity which focuses on the work itself, and executive activity which concerns discussion related to the management of the project or of the conference call itself. Clarifications were shown to be central to both executive-level and work-related activities during these telephone conferences, suggesting that synchronous telephone communication is the principal medium for generating mutual understanding and resolving conflicts. Activities commonly associated with software design or similarly detailed technical work did not play a central role in conference call discussions. It is also clear that conference calls have the advantage of rapid response time and can facilitate high-level planning, setting agendas, and motivating work.

Each of the conference calls can be characterized by the number of participants, the level of active participation, the topical structure (subjects of discussion), the goals generated, and decisions taken. This analysis can be related to various other outcomes such as the timely completion of a task. Over the course of time, the conference calls generally became more work-oriented and focused, indicating a greater level of shared understanding. The calls are further embedded in a particular activity pattern. They are usually preceded by a flurry of e-mail messages that address both content-related issues (e.g., guideline issues) and agendas for the upcoming call. The calls then serve to chart and refocus activity, often leading to further differentiation of individual and team responsibility. This leads to e-mail communication which serves to summarize the calls and to delineate further the specific issues that had been discussed and consensus that had been reached. The details, especially those of a technical nature, are best handled through e-mail.

7. Conclusions

The Internet is well established as a tool for collaborative research in areas such as nuclear physics and biotechnology. With its increasing role in medicine, it has been natural for the Internet to become a tool for collaborative medical informatics

research. We have sought to understand aspects of collaboration which are well-supported by Internet facilities such as e-mail and the World Wide Web, and which are best-supported by synchronous communication via face-to-face meetings or telephone conference calls, viewing InterMed as an ongoing experiment in computer-mediated collaborative design. We have sought to understand this design process, and the role of the Internet as a medium for such an endeavor, as reported in this paper and elsewhere [2,8]. Evaluating a collaborative design process necessitates an analytic framework for understanding how the various activities lead to constructing distributed representations, task environments, problem spaces, and cognitive strategies. We hope that the framework we have devised will also facilitate the iterative design-implementation-evaluation process for other domains.

Formative evaluations of the sort we have described here can play a crucial role in the evolution of a collaborative activity such as InterMed. As has been noted, insights from McGill's e-mail interviews helped to solidify the PIs' decision to convert the group's energies from vocabulary work to the development of a shared representation for clinical guidelines. Furthermore, we have learned how best to leverage the various communications options available to us, matching specific technologies to the kinds of tasks for which we have found they are best suited. It is clear that e-mail and use of the Web are inadequate mechanisms for the development of an effective collaborative activity; they must be complemented by occasional face-to-face meetings and by conference calls during which clarifications and executive oversight can be facilitated most effectively. With proper use of conference calls and occasional meetings, however, e-mail and other Internet technologies can play a remarkable role in supporting collaboration at a distance [2,21].

Electronic collaboratories offer great opportunities for unparalleled progress in science as well as in other disciplines [23,24]. There are still numerous technological, sociocultural, and cognitive challenges to be met. InterMed to a large extent reflects both the promise and challenges. This new form of collaborative enterprise is still in its infancy. Genuine collaboration requires a high-level of sustained commitment, which necessitates much effort [12]. However, the payoff can be substantial in that the collective can achieve objectives that the individual teams cannot achieve through simple cooperative work. A collaboratory, like other institutions, develops a particular approach which characterizes recurrent work-activity and communication patterns. Some of the patterns are more effective than others and part of the growth of the collaboration occurs as participants discover those patterns and make them routine elements in their work activities and communications. One of our ongoing central research objectives is to describe and understand these patterns so that communication and successful outcomes can be facilitated.

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Med Collaboratory may be found at the following URLs: Brigham and Women's Hospital/Harvard: http://dsg.harvard.edu/public/intermed/lnterMed_Collab.html; Columbia Presbyterian Medical Center: http://www.cpmc.columbia.edu/intermed_proj.html; Massachusetts General Hospital/Harvard: http://www.lcs.mgh.harvard.edu/; McGill University: http://www.psych.mcgill.ca/perpg/fac/patel/intermed.html; Stanford University School of Medicine: http://www.smi.stanford.edu/projects/intermed-web

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