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Knowledge Barriers to Diffusion of Telemedicine

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Abstract

Telemedicine is one proposed solution to problems of accessibility, quality, and costs of medical care. Although telemedicine applications have proliferated in recent years, their diffusion has remained low in terms of the volume of consultations. In this study, Attewell's (1992) theory of knowledge barriers is extended to explain why diffusion of telemedicine remains low. In case studies of telemedicine programs in three world-renowned medical centers in Boston, Massachusetts, we find that, in addition to technical knowledge barriers, as suggested by Attewell, there are economic, organizational, and behavioral knowledge barriers that inhibit the diffusion of telemedicine. The lowering of these barriers entails intensive learning efforts by proponents of applications within adopter organizations. They need to develop technically feasible, medically valid, reimbursable, and institutionally supported applications in order to justify the value of telemedicine and engender frequent and consistent use by physicians.

Keywords: Diffusion of innovation, medical information systems, case study.

1. INTRODUCTION

The U.S. health care system is confronting major problems in accessibility, quality, and costs of medical care (Bashshur 1997). Telemedicine, broadly defined as the use of information technology (IT) to deliver medical services over distances, is one proposed solution to these problems (OTA 1995). Although telemedicine applications that use videoconferencing and various image processing, transmission, and storage technologies have proliferated in recent years (Grigsby and Allen 1997), the volume of actual telemedicine consultations has remained low (Hassol 1996). One common explanation points to problems in reimbursement for telemedicine consultations (Grigsby and Allen 1997). However, a nationwide survey of rural hospitals found no association between reimbursement and utilization of telemedicine (Hassol 1996). Why diffusion of telemedicine remains low is yet to be explained.

Prior research on the diffusion of complex IT applications suggests that the burden of learning technical knowledge creates "knowledge barriers" that can inhibit diffusion (Attewell 1992; Fichman and Kemerer 1997). Adopters must engage in

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considerable technical learning in order to diffuse applications. This learning is conceptualized as knowledge acquisition or distribution, i.e., making "knowledge available where it previously was not" (Pentland 1995, p. 18). In this paper, we argue that the acquisition of technical knowledge is necessary but not sufficient to diffuse telemedicine. In case studies of telemedicine diffusion at three academic medical centers in Boston, Massachusetts, we found that economic, organizational and behavioral barriers also inhibited diffusion and required extensive learning. We extend Attewell's theory to include these other types of knowledge barriers. We also argue that the diffusion of a new and complex IT such as telemedicine is a process of *de novo* knowledge creation and justification within each adopting organization. Proponents of telemedicine must overcome all knowledge barriers and convince relevant stakeholders (e.g., physicians, insurers, regulators, etc.) that the technology "works" for their specific settings and work practices.

2. THEORETICAL BACKGROUND

As a new medical practice, telemedicine can be conceptualized as an innovation (Rogers 1995). Early theories on diffusion of innovation have been inadequate for understanding the diffusion of information technologies that have complex scientific bases or which demand extensive hand-holding (Eveland and Tornatzky 1990). Attewell's theory of knowledge barriers specifically addresses this criticism and maintains that diffusion is a learning process whereby adopters must overcome technical knowledge barriers and acquire requisite know-how and skills. Mediating institutions (e.g., service bureaus, consultants, and vendors) distribute technical knowledge to adopters by helping them purchase and install complex technologies, design and code software, troubleshoot problems, and develop workarounds (Attewell 1992). After adoption, they continue to provide technical knowledge through documentation, help wizards, how-to videos, and technical support lines.

This perspective has been particularly useful in understanding diffusion of business computing (Attewell 1992) and software process innovations (Fichman and Kemerer 1997). However, it has a number of limitations. First, it focuses primarily on the initial stages of diffusion where in-house knowledge is scant and can be acquired from outside. The knowledge creation process—where organizational members attempt to learn about and customize new technologies to fit their own practices—is given less attention. Second, it assumes that the key challenge in the diffusion of new ITs is the lowering of technical knowledge barriers. Economic, organizational, and behavioral barriers are given short shrift despite the critical roles that they may play in the diffusion.

In the case of telemedicine, few mediating organizations are available to distribute technical knowledge and the barriers to diffusion are not solely technical (Anderson 1997). Because telemedicine is so new, many stakeholders do not understand how it will work in their particular contexts and, therefore, need to be convinced of its value before they will accept it.

Economic arrangements, for example, have to simultaneously satisfy a number of stakeholders. Medical centers may invest in telemedicine to reach out to new patient markets. However, they will not realize the proposed economic benefits until physicians regularly use it. Physicians won't use the new technologies until business models that guarantee reimbursement have been developed (Fendrick and Schwartz 1994). Insurers will only agree to reimburse telemedicine consultations when cost-effectiveness has been proven.

Further, new clinical information systems like telemedicine alter organizational arrangements such as traditional medical practice and workflow (Anderson 1997). Successful diffusion of applications requires development of new organizational procedures and integration into extant organizational settings (Cooper and Zmud 1990). The social organization of medical centers may also undergo change (Anderson 1997). The distribution of resources and power may be affected as well as interdepartmental relations (Markus 1983). For example, who "owns" the new technology may impact the types of institutional support mechanisms (e.g., centers, spin-offs, new roles and structures) to be established and their relative influence within the organization.

Finally, the use of telemedicine in clinical settings may necessitate behavioral changes. For example, physicians may have to diagnose patients over a video link rather than face-to-face. Physicians may resist telemedicine if they perceive that medical diagnoses will be degraded or if their work roles, status, or autonomy will be adversely affected (Anderson 1997). Poor system design and the context of use may also create physician resistance (Markus 1983).

We argue that, to overcome these barriers, proponents of telemedicine (i.e., technically savvy physicians, IT professionals, and manager-entrepreneurs) must create new knowledge not only *about* the technology, but also about the economics of telemedicine (e.g., new business models), its organizational impacts (e.g., for workflow), and how to handle behavioral changes (e.g., in clinical use). This new knowledge can then be used to convince organizational stakeholders that the technology works in their setting.

Prior research has distinguished between two general sources of learning: by example or by experience. Pentland argues that the distinction between the two closely parallels conceptual differences between knowledge distribution and creation. As noted above, Attewell focuses primarily on technical knowledge distribution and diffusion through mediating organizations while we focus primarily on knowledge creation.

Miner and Mezias (1996) have further refined the concept of learning by developing a typology. One type, vicarious learning, is similar to learning by example. The other three types, trial and error, inferential, and generative, each successively requires more reflection and systematic deduction about why behaviors have specific outcomes. Generative learning, in particular, is seen as embodying essential knowledge creation processes. We expect to find a variety of types of learning throughout the diffusion process whereby proponents and potential adopters socially construct the "working" of a technology (Bijker 1997).

Following Nonaka's (1994) definition of knowledge as "justified true beliefs," we expect that beliefs and learning of proponents would require ratification by potential adopters before they can be accepted as new knowledge. In discourse and interaction with potential adopters, proponents may use different epistemic criteria to justify their knowledge claims. Pentland identifies four types of commonly used justification criteria: (1) ritual/superstitious, i.e., a blind faith that a given action has a beneficial consequence; (2) authoritative, i.e., statements of a trusted, respected or feared individual; (3) pragmatic, i.e., practical success; and (4) scientific, i.e., acceptable standards and rigor in a given field of inquiry. These criteria serve as rhetorical resources for proponents in convincing others of their knowledge claims about telemedicine. We expect that some epistemic criteria will be more persuasive than others.

3. METHODS

There is a paucity of research on the diffusion of telemedicine, which is a relatively new and complex phenomenon. We chose the case study method, as suggested by Benbasat, Goldstein and Mead (1987) and Yin (1994), as our study involves "how," "why," or explanatory "what" types of questions. We designed a longitudinal, embedded, multiple case study to understand telemedicine at two levels (programs and individual applications) and to increase robustness of our findings through a logic of literal replication (Yin 1994).

Our research setting is Boston, Massachusetts, a city that hosts three world-renowned medical schools and 25 high-tech orientated hospitals (AHA 1997). According to Rogers (1983) "gravity model," innovations are likely to appear and diffuse quickly in centers like Boston, making it an appropriate setting to study the diffusion of telemedicine.

In September 1996, we conducted 29 telephone interviews with senior managers of all hospitals in Boston to learn if they had adopted telemedicine and why. Six hospitals had active telemedicine initiatives. We interviewed the managers of these initiatives between October and mid-December 1996. These two phases enabled us to select Partners Healthcare System, Inc. (Partners), BetaCare, and GammaCare (pseudonyms) as our longitudinal sites (Pettigrew 1989). Each site had an active institutional telemedicine program older than one year and willing participants for our study.

Through May 1997, we collected data at the three sites through semi-structured interviews, observations, and document review. We interviewed knowledgeable people in each telemedicine application until no other potential informant was mentioned. Informants included managers, physicians, technologists, and administrators involved in applications. Using an interview protocol, we asked them open-ended questions about: (1) their telemedicine program and (2) the telemedicine applications in which they were involved. We completed 45 interviews. Each took an average of 45 minutes. All interviews were tape recorded and transcribed. We also observed meetings and telemedicine procedures and reviewed documents, including internal communications, meeting agendas, business plans, and technical details of equipment.

We identified temporal patterns in the data and wrote up chronological descriptions. Principal informants confirmed our accounts except for some minor suggestions that were incorporated into the cases where appropriate. We conducted within case and cross-case analyses using an iterative explanation-building process (Yin 1994).

We assessed diffusion at two levels. At the telemedicine program level, we looked at the number of applications and the number of users involved in the program. At the application level, we looked at usage patterns and the annual volume of consultations.

4. PARTNERS

Partners is a network of teaching, community, and specialty-care hospitals, and primary care practices in Massachusetts. It was established as an umbrella organization when Massachusetts General Hospital (MGH) and Brigham and Women's Hospital merged in 1994. During the 1960s, MGH pioneered telemedicine. However, when government grants were discontinued, it could no longer sustain the program.

Telemedicine began anew in 1988, when Dr. Thrall, chief radiologist at MGH, started a teleradiology project, RSTAR (Radiology Storage Transfer Analysis Reporting), to reduce film storage costs and to sell their radiology expertise to remote locations. According to Dr. Thrall, RSTAR meant "converting the work process of the first 100 years of radiology into a totally different work process." Radiologists had to view digitized films on a computer screen instead of viewing films on a light-box. Their acceptance was crucial since "the most expensive component of a telemedicine system is the physician."

Dr. Thrall formed a project team of radiologists who were advanced users of medical imaging technology. The team demonstrated a commercial picture archiving and communications system (PACS) to obtain physician reaction. Radiologists found PACS difficult to use, slow in displaying images, and poor in image quality. They preferred viewing films on a light-box. To develop an acceptable system, the team collaborated with their IS department, a local phone company, the Massachusetts Institute of Technology Media Lab, consultants, and vendors. They used cutting-edge technologies, e.g., a film digitizer, optical jukebox, high-resolution workstations, image server, an Ethernet LAN coupled with a fiber optic LAN, and a bridge to interface with remote sites over T-1 (1.54 Mbps) lines. RSTAR was developed in about three years. According to Dr. Thrall, radiologists were happy with image quality, response times and the system's ease of use.

The team conducted a study that showed a 98% concordance rate between interpretations of plain films and corresponding digitized films on the RSTAR (Goldberg et al. 1993). Dr. Thrall reported, "All of the radiologists saw that they could interpret images off the workstation accurately, and we were able to begin inviting more and more radiologists to take part in teleradiology."

At this time, radiology departments were losing revenue due to Medicare payment cutbacks. According to Dr. Thrall, "teleradiology was seen as a way of importing work into the department." He worked with physician organizations at MGH to spin-off two subsidiaries. A subsidiary, also named RSTAR, developed and commercialized the RSTAR. Another subsidiary, WorldCare, sold their radiology expertise.

Dr. Thrall and WorldCare explored new markets. In domestic markets, there were regulatory barriers such as prohibition of telemedicine across state lines and limited reimbursement for consultations. International markets, like the Middle East, were not regulated. Affluent patients were willing to pay for telemedicine consultations. However, many international sites lacked high-bandwidth lines. Dr. Thrall also uncovered a demand for telepathology and convinced pathologists to develop a system for doing international telepathology.

By early 1994, the radiology team had successfully applied a wavelet-based compression technique to radiographic images to achieve an average compression ratio of 23:1 (Goldberg et al. 1994a). Pathologists had also developed a system. MGH demonstrated the two systems between the U.S., Saudi Arabia, and United Arab Emirates. Compression did not degrade the diagnostic quality of radiographic images. Resolution of pathology images was also good. However, the bandwidth of POT lines was still too low to exchange rich pathology images. A study was published that demonstrated the first use of POT lines for international telemedicine (Goldberg et al. 1994b).

Medical specialties, which rely on radiographic images, could use RSTAR to sell expertise to international sites. Within six months, WorldCare linked eight international sites to MGH via RSTAR. By March 1995, MGH conducted 750 consultations in radiology and 150 consultations in other medical specialties.

The publication of scientific studies about RSTAR and the revenue generated from international consultations increased interest in telemedicine. Chiefs of dermatology and psychiatry assessed the feasibility and validity of telemedicine in their own specialties. Dr. Thrall encouraged interested physicians to come together to talk about their telemedicine projects. Over time, an ad hoc telemedicine committee emerged out of these informal interactions.

In early 1995, Dr. Kvedar, a young dermatologist leading the teledermatology research, took the helm in the committee. The thriving international telemedicine business needed support. The committee created three new positions: telemedicine coordinator, teleradiology coordinator, and teleradiology director. Operational procedures were developed for triaging incoming cases to physicians and ensuring that cases were turned around within set time limits. The committee invited other physicians to participate to meet the growing demand from international sites. Physician response was positive; they earned additional fees and could see rare medical cases from different parts of the world.

The need for institutional support continued as the volume of consultations increased. The committee prepared a strategic plan. In the fall of 1995, MGH administration accepted the plan, approved the establishment of a Telemedicine Center, and appointed Dr. Kvedar as the director. After a year, the CIO of Partners offered to take the center into the IS department. He envisioned telemedicine as part of the daily medical practices of the hospital by the year 2000.

The center instituted departments to manage telemedicine operations, to conduct R&D on new telemedicine applications, to identify standards for telemedicine, and to explore remote education possibilities. It also established two telemedicine committees, the MGH Telemedicine Committee and the Partners Advisory Committee.

Membership in the center and committees grew. A center manager commented on the MGH Committee, “It is one of the very few committees that I have seen in my life that actually grew in time as opposed to turning inactive over time.” A research assistant reported, “At this center, every single department that we have is growing.”

As of May 1997, teleradiology was used routinely in domestic and international markets. All 65 radiologists were using the system to conduct about 3,000 consultations annually. Forty physicians (10% of MGH physicians) were using international telemedicine to conduct about 400 consultations annually. In telepathology, pathologists were still investigating ways to transmit rich images within bandwidth constraints. In teledermatology and telepsychiatry, feasibility and validity studies were published (Kvedar et al. 1997; Baer et al. 1995). Dr. Kvedar reported, however, that these applications were not deployed due to lack of appropriate business models, “It [teledermatology] has to make sense either through a capitated model, or through a fee-for-service model. Currently, there are not either….So, it hasn’t become part of the day-to-day for the [dermatology] department.” A telepsychiatry researcher reported, “In general, the problem for everyone today is proving cost-effectiveness.” The head of a digital echocardiography lab commented on physician reaction to telecardiology, “They [cardiologists] don’t trust the technology.” At the conclusion of our study, Partners was undertaking R&D on several new applications and was rolling out videoconferencing units.

5. BETACARE

BetaCare is the teaching hospital of a world-renowned medical school in Boston. In 1990, BetaCare received a grant from the local phone company to develop a telecardiology application for testing a new wide area fiber-optic network known as media broadband services (MBS). The CIO at the time and the chief of cardiology led the development effort. The idea was to exchange angiography images with remote locations using the MBS. The application would enable physicians to interact on-line through a voice channel with a capability to annotate on the exchanged images. The current CIO commented on the system problems, "It was big UNIX workstations with a T3 pipe [45 Mbps] to do cardiac angiography. It never worked! It was incredibly expensive!"

The IS department partnered with an engineering firm to explore low-cost, standards-based telemedicine solutions. The technical telemedicine coordinator reported, "The idea was to make it [telemedicine] cheap enough so that experiments can be done without huge pockets of money." In six months, the IS department, the cardiology department and the engineering firm developed a desktop videoconferencing system that could digitize cardiac images off of angiography units, compress them and send them to remote locations off-line as multimedia electronic messages. The new system was less expensive, standards-based, and required less bandwidth since it exchanged images off-line. However, it still ran on the expensive MBS infrastructure. The next challenge was to find cheaper ways of exchanging images.

The CIO explored use of ISDN technology to meet their transmission needs at affordable costs. Tradeoffs between bandwidth and image quality were found through trial and error. The CIO reported that they did not undertake scientific studies to assess the medical validity of the system, "We have never seen this [telemedicine] as a research project… it is just part of our business." He asked some senior physicians to judge the quality of the images and reported, "I have never had one doctor ever complain about quality."

In early 1995, the system was demonstrated to the chiefs of clinics. Many of them wanted to gain access to new patient markets. The CIO worked with them to conceptualize clinical applications. He stated, "We identify clinical needs and develop a business model." The IS department and engineering firm customized the system for telecardiology, international telemedicine, teleophthalmology, telepsychiatry, nursing home, home health, and fetal telemedicine applications. Each clinic pursued its own application. The CIO reported, "We have never tried to make telemedicine an institutional program."

Business models envisaged for telecardiology, teleophthalmology, telepsychiatry, nursing home and home health applications could not show reimbursement for consultations during the trials. The chiefs of clinics discontinued clinical use of these applications.

International telemedicine was successful in generating revenue and engendering adoption by physicians. The CIO reported, "The fact that we are making so much money doing telemedicine, has of course made it very popular." However, many physicians were not comfortable using the technology. The medical coordinator commented, "Physicians are some of the most technophobic people that you will ever meet." Technical and medical coordinators scheduled sessions, initiated ISDN connections, and helped physicians. As of March 1997, about 40 physicians (10% of physicians) were using the application to conduct about 200 international consultations annually.

In fetal telemedicine, the CIO and some obstetricians became convinced of the profitability of an application during initial trials. However, they realized that before moving the application into clinical use, they had to justify its medical validity and cost-effectiveness to the national society that accredits fetal telemedicine sites and to insurance companies that would reimburse consultations. Even though they did not routinely do scientific studies, in this case, the physicians believed it was necessary. One obstetrician reported, "The studies that we did to validate telemedicine have provisionally been accepted for two of our journals." Then, they started defining how a typical session would be conducted. There were two possibilities: (1) on-line video connections or (2) off-line image storage and transmission. Each had different implications for the daily routine of the clinic, the volume of cases that could be served, staffing requirements, and cost-effectiveness. One obstetrician commented, "We have to do traffic-flow type of studies before we can say whether it is cost-effective." As of March 1997, all physicians in the clinic were using the application. They were conducting about 1,000 consultations per year in their research studies, and they expected the volume to grow dramatically when the application is offered as a commercial service.

6. GAMMACARE

GammaCare is a network of teaching and community hospitals and physician groups in Massachusetts. In mid-1994, the head of media services proposed to link member institutions via telemedicine to enable “a seamless integration of care so that wherever the patients happen to be, they are part of the [GammaCare] system.” With the support of the CIO, a vice president, and some physicians, he prepared a business plan that outlined a phased implementation starting with demonstrations of telemedicine between two hospitals and then expanding into all member institutions. The administration accepted the plan, provided funding for exploration of the technology, and appointed the head of media services as the telemedicine project manager.

In early 1995, GammaCare acquired two group videoconferencing systems. The project manager convinced a staff member of media services and a young cardiologist to serve as the technical and medical telemedicine coordinators. As proponents of telemedicine, their roles were to identify physician champions and site coordinators at member institutions and provide administrative and technical support. They exposed physicians to the technology through demonstrations and educational and administrative teleconferences.

Early adopters included a world-famous liver transplant surgeon at a teaching hospital, two site coordinators at a community hospital, and a few young physicians. The two hospitals were linked in early 1995. Physicians at the community hospital had access to educational tumor conferences at the teaching hospital via teleconferencing. They conducted about 30 such tumor-board conferences until mid-1996. The surgeon also provided a few (three or four) consultations to patients at the community hospital by reviewing their X-rays and interviewing them over the video link. This application was called “rare tumor consults” since the surgeon specializes in rare tumors. The surgeon reported, “I look at this as really an incredible way to interview patients, look at their films, talk things over with them.” Although he receives seven or eight rare tumor cases per week from around the world, he cannot use telemedicine since referring physicians lack access to the technology.

In mid-1995, the community hospital lost its cardiology coverage. Third year fellows from the teaching hospital commuted to the community hospital to cover emergency and intensive care units (ICUs). These young, computer literate physicians used the technology to exchange X-rays, MRIs, echocardiography, etc. with the medical telemedicine coordinator at the ICU of the teaching hospital. The president of the community hospital reported, “They were using the technology like the telephone…. ‘Here look at this, look at that, OK? I am going to send you the echo! Here is the EKG strip!’” They conducted about 30 to 40 ICU-to-ICU consults. The coordinator expressed satisfaction with the technology: “By and large, major decisions can be made using the current technology.”

Another member teaching hospital soon acquired a videoconferencing unit and connected to the two hospitals. Anesthesiologists, technicians, and nurses from the two teaching hospitals started doing teleconferences to conduct their regular educational and administrative meetings. They conducted about 30 such meetings.

The feasibility of conducting pre-surgery interviews with patients over videoconferencing was tested. This application would enable patients to go to their nearest member institution for their interviews, thus enhancing the completion of interviews and reducing costly surgery cancellations. Nurses interviewed two mock-patients at the community hospital. Although they were happy with the video interviews, they stated that incorporating telemedicine into their daily routines would be a challenge: “You couldn’t just have so many [video] calls up in the middle [of serving patients here].” Cost-effectiveness of the application was not clear. The technical telemedicine coordinator reported, “At this point, we have not proved that [it] pays.”

In the summer of 1996, the project manager and coordinators evaluated their experiences, prepared a phase-II business plan, and put together a telemedicine executive committee. After two years with telemedicine, the project manager reported that most physicians still saw telemedicine as a “toy” rather than a clinically useful technology: “[T]he easy part is the technology….The much tougher part is really getting people to collaborate together on a regular basis, not just to play around with the toy but to do work together.” A site coordinator reported, “[Telemedicine] is still a technology that people are leery of in terms of how it can be used and how valuable it is.”

Table 1. Knowledge Barriers to Diffusion of Telemedicine[1]

Site	Applications	Knowledge Barriers: Technical	Economic	Organizational	Behavioral	Diffusion: Usage	Volume[2]
Partners	Teleradiology	Lowered[3]	Lowered	Lowered	Lowered	Regular	3000
	International Telemedicine	Lowered	Lowered	Lowered	Lowered	Regular	400
	Telepathology	Bandwidth	None[4]	Protocols	None	Research	-
	Teledermatology	Lowered	Business model	Lowered	Physician resistance	Research	-
	Telecardiology	Image quality	Business model	Support	Physician resistance	Sporadic	-
	Telepsychiatry	Lowered	Cost-effectiveness	Lowered	Physician resistance	Research	
BetaCare	Telecardiology	Image quality	Business model	Support	Physician resistance	Sporadic	-
	Teleophthalmology	Lowered	Business model	Support	Physician resistance	On-hold	-
	International Telemedicine	Lowered	Lowered	Lowered	Lowered	Regular	200
	Telepsychiatry	Lowered	Business model	Support	Physician resistance	On-hold	
	Nursing home	Lowered	Business model	Support	Physician resistance	On-hold	-
	Home health	Lowered	Business model	Support	Physician resistance	On-hold	-
	Fetal telemedicine	Lowered	None	Protocols	Lowered	Research	1000
GammaCare	Rare tumor consults	None	None	Critical mass of users	None	Sporadic	-
	ICU-ICU consults	None	Business model	Support Protocols	Physician Involvement	On-hold	-
	Pre-admission testing	None	Cost-effectiveness	Workflow	None	On-hold	-
	Telepsychiatry	None	Business model	Protocols	None	Research	-

[1] Snapshot in May 1997
[2] Annual
[3] Barrier addressed and lowered
[4] No barrier is perceived yet

The project manager recognized challenges in making telemedicine work:

> [I]t is really easy to do administrative applications…. Educational is also fairly easy….But, clinical stuff is much more complex: You have to deal with reimbursement; you have to deal with clinical care; you have to deal with patients; you have to deal with physicians; you have to deal with infrastructure; you have to deal with, you name it!

He described the next step: "We need to show them the real solutions as opposed to demonstrations." The telemedicine initiative started drifting in October 1996, however, when the major teaching hospital merged with another hospital in Boston. Teleconferences came to a complete halt. In early 1997, however, the initiative started up again when a telemedicine executive committee started monthly meetings. The committee decided to initially develop a telepsychiatry application to use as a blueprint for developing additional clinical applications. Telepsychiatry was selected because the chief psychiatrist of a community hospital, also a committee member, was interested in the application.

7. DISCUSSION

Our study shows that four types of knowledge barriers need to be lowered for telemedicine applications to diffuse. Table 1 provides a snapshot of perceived knowledge barriers for applications at our sites at the end of our data collection, in May 1997.

Below, we summarize our findings about the knowledge barriers and the particular types of learning and epistemic criteria used for lowering them.

Technical: Technical knowledge barriers refer to the burden of learning technical know-how and skills (Attewell 1992). In this study, we found that lowering these barriers is critical in the development of technically feasible telemedicine applications. Partners, for example, after demonstrating a commercial PACS, learned that they had to develop their own systems if applications were to be acceptable to physicians. They eventually spun off a development organization to shift this learning burden outside of the organization. BetaCare started out with the MBS of a local phone company. They soon learned that they had to customize commercial applications in-house for clinical use. They formed IS and engineering teams to work on applications with clinical specialists. GammaCare, on the other hand, never went beyond the implementation of a commercial videoconferencing system. They had not yet engaged in (or even recognized) the technical challenges involved in customizing commercial video-conferencing equipment for clinical use. Unlike the diffusion of business computing and process innovations, where technical knowledge could be acquired from outside, telemedicine proponents at our sites had to learn technical know-how and skills themselves through trial and error (e.g., the tradeoffs between bandwidth and image quality), inferential, and generative learning within their own organizations.

Our data indicates that unless technical feasibility is accompanied by medical validity, physicians are not convinced of the value of applications. Proponents relied on two types of epistemic criteria to claim medical validity. Partners conducted scientific studies whereas BetaCare relied on authoritative statements of senior physicians to convince their physicians that telemedicine applications do not degrade diagnostic quality of images. Scientific criteria proved to be more effective for justification of medical validity. While authoritative criteria convinced some physicians to try an application, they were insufficient to engender regular use. BetaCare was just realizing the importance of scientific criteria in moving applications to regular use.

Economic: Economic knowledge barriers refer to lack of know-how in developing business models that satisfy all stakeholders. The major concern at our sites was to satisfy physicians by reimbursing their telemedicine consultations and/or opening up new patient markets. For example, at Partners, teleradiology compensated for cutbacks in Medicare payments by importing more work into the department from remote markets. Business models were developed through inferential learning and were justified when they actually generated revenue. However, this pragmatic knowledge had to be accompanied by scientific evidence of cost-effectiveness when applications involved regulatory agencies and insurers.

Organizational: The burden of learning how a new technology can be integrated into extant organizational settings and how its regular usage can be instsitutionally supported constitutes organizational knowledge barriers. In our sites, proponents instituted new technical, administrative, and medical support services, and integrated telemedicine procedures within extant workflow through trial and error, inferential, and generative learning. For example, Partners learned how to integrate telemedicine into its organizational procedures during its studies on medical validity. Research protocols used in these studies were revised and adapted as new procedures for conducting telemedicine consultations. Pragmatic success of the new procedures was sufficient to make them part of the daily routine. Similarly, BetaCare was undertaking traffic-flow studies in fetal medicine to decide how to conduct consultations in the most cost-effective way.

Behavioral: The burden of learning how to change physician behavior and manage issues of resistance, power, and politics around telemedicine constitutes behavioral knowledge barriers. In our sites, proponents went through this learning implicitly throughout the diffusion process. When technical barriers were being lowered, they had to convince physicians that the application would be easy to use and would provide accurate diagnosis. Then, they had to align incentives for various stakeholders and convince physicians that the application provides reimbursement and/or opens up new patients markets. Finally, they had to convince physicians that the institution provides adequate support services for them to use the application without significant disruption of their daily routine. Through an iterative process of observing reactions of physicians and other stakeholders, and responding with revisions, new models and routines, proponents eased the change from traditional to telemedicine practices.

7.1 Lowering Knowledge Barriers

Our studies indicate that telemedicine applications diffuse when all knowledge barriers are lowered. Lowering knowledge barriers is a dynamic learning process that cannot be represented by a sequential stage model (Wolfe 1994). However, knowledge barriers that predominated the learning activities of proponents suggest a temporal learning pattern (Hughes 1987). Proponents first try to lower technical barriers by developing a technically feasible and medically valid application. When they succeed, they proceed to develop a business model that will align incentives for all stakeholders. However, their primary concern is to satisfy physicians by reimbursing telemedicine consultations. A technically feasible, medically valid, and reimbursable application engenders adoption and usage by physicians. As adoptions and usage increase, the need for systematic organizational support services also increases. Thus, proponents start developing new workflow and organizational support mechanisms. An institutionally supported telemedicine application increases the chances of further adoptions and usage. Behavioral knowledge barriers are implicitly addressed throughout the diffusion process since the technical, economic, and organizational issues mentioned above all influence physician adoption and usage of applications.

There were also overlaps, feedback and feed-forward cycles among the learning processes. Proponents moved back and forth among the four knowledge barriers until all barriers were lowered (see Table 1, “regular” use applications) or some barriers remained and adoption was discontinued (“on-hold” applications). However, many proponents were still struggling to lower knowledge barriers (“sporadic” and “research” applications) at the conclusion of our study.

7.2 Why Success?

Diffusion was high at Partners: two applications were regularly used, had high volume consultations, and the number of physicians using them was increasing. Technical knowledge barriers were reduced through in-house R&D in collaboration with external organizations. Medical validity was justified through scientific criteria. The two firms spun off for commercialization of the technology developed business models that generate revenues. Encouragement of innovative young physicians to explore and experiment with telemedicine led to proliferation of new applications and institutionalization of telemedicine.

At BetaCare, diffusion was moderate. International telemedicine was in regular use, but the volume of consultations was low. Fetal telemedicine was taking off, but organizational and economic barriers remained. Project teams lowered technical barriers by customizing the technology to clinical applications. Business models were developed through trial and error and inferential learning. Applications that proved successful in generating revenue were continued. Although authoritative criteria initially engendered adoptions, they were not enough to convince physicians of the medical validity of applications. Usage of applications was sporadic and the number of people using them was declining.

At GammaCare, diffusion was low. At the end of two years, there was no active telemedicine application. Although the technology was used periodically for educational and administrative teleconferences, it had not diffused into medical practice. Physicians saw telemedicine as a nice "toy" rather than a clinically useful technology. Technical feasibility, medical validity, and profitability of applications were yet to be learned and demonstrated.

In summary, the success of telemedicine programs depended on proponents' ability to lower technical, economic, organizational, and behavioral knowledge barriers. Much of the learning had to be done *de novo* at each site since the know-how was not readily transferable from the market as in the case of business computing (Attewell 1992). Experiential learning to lower the four knowledge barriers and ratification of knowledge claims through scientific and pragmatic criteria were most effective in constructing the "working" of a telemedicine application.

8. CONCLUSIONS

Despite its potential to lower costs and improve access to healthcare, technical, economic, organizational, and behavioral knowledge barriers inhibit diffusion of telemedicine. The burden of lowering these barriers is placed squarely in adopter organizations since few mediating institutions are available in the market. Today, the most successful sites are those that develop systems, business models, workflow and institutional support for telemedicine applications *de novo*. As academic medical centers with many enthusiastic and skilled proponents, our sites are typical of early adopters. While mediating institutions may emerge over time, given the burden of learning, we do not expect telemedicine to diffuse broadly in the near-term.

Theoretical Implications. In this study, we extended Attewell's notion of knowledge barriers to diffusion to include economic, organizational, and behavioral knowledge barriers in addition to technical barriers. Our study suggests reconceptualization of diffusion as a social process whereby proponents learn about the "working" of a technology through various learning processes and justify their learning to potential adopters as new knowledge using various epistemic criteria. In this study, we began examining the types of learning processes and justification criteria that might be effective in lowering knowledge barriers and diffusing applications. Our approach is novel in that it conceptualizes and categorizes the learning associated with diffusion of complex information technologies into four types of knowledge barriers. This learning, or lowering of knowledge barriers, constitutes the "working" of a new technology in an organizational context. We believe that the extended notion of knowledge barriers may be useful in understanding the diffusion of complex information technologies beyond telemedicine.

Practitioner Implications. Our study shows that ad hoc demonstrations and experimentation with commercially available systems are insufficient to diffuse telemedicine innovations. Applications need to be developed or extensively customized within host organizations. Two mechanisms have proven to be successful: technology development spin-offs or in-house project teams comprised of IT specialists, engineers, and clinical physicians. Proponents also need to develop new business models. Telemedicine reimbursement is problematic under standard healthcare financing models, for example, fee-for-service and capitated models. Multiple stakeholders need to be considered: physicians, patients, insurers, regulators, and medical institutions. To maintain high volume telemedicine procedures, new workflow and organizational support mechanisms need to be instituted. Scientific criteria, i.e., publication of research in peer-reviewed medical journals, as well as pragmatic success of business models and new organizational routines are most persuasive in convincing physicians to use a new application.

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