Adaptation as Design: Learning from an EMR Deployment Study

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ABSTRACT
We conducted an observational study in an Emergency Department (ED) to examine the adaptation process after deploying an Electronic Medical Records (EMR) system. We investigated how EMR was adapted to the complex clinical work environment and how doctors and nurses engaged in the adaptation process. In this paper, we present three cases in which ED clinicians designed workarounds in order to adapt to the new work practice. Our findings reveal a rich picture of ED clinicians' active reinterpretation and modification of their work practice through their engagement with the system-in-use and its organizational and physical context. These findings call for the adaptation period in designing a socio-technical system in healthcare settings to be critically considered as an active end-user design process, a negotiating process, and a re-routinized process.

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Electronic Medical Record (EMR); Implementations; Adaptation; Workaround; Design; Clinical Practices;

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INTRODUCTION
Although designers tend to envision their carefully designed systems as being usable immediately after deployment, previous studies have found that it often takes time for users to learn and adapt to the new technology-in-use [24,27,33]. This period is often referred to as technological adaptation and is considered necessary in system deployment. Adaptation has been defined as a process intended to modify the new technology or relevant aspects of the operating context including users' skills or procedures [33]. In studying the technology adaptation period, certain studies have focused on the adaptation of user behaviors [7,10,15]; others have studied how technologies are modified by users [24,27,33, 35].

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In the healthcare domain where the current study was conducted, despite huge financial and time investments, the use of large Health IT systems, including the Electronic Medical Record (EMR) system, are not always perceived as successful. Prior studies have revealed unintended consequences after system deployment, such as increased documentation time [12, 28], system induced medical errors [1, 22], more interruptions to clinical workflows [30] and workflow incompatibilities [12]. To solve these problems, clinicians often use different workarounds to adapt to new work processes or to bypass the deficiencies of new technology. However, clinician workarounds reported in prior studies [23, 2,34,35] mostly focused on the impacts on clinical work practices, instead of focusing on the process of how these workarounds were designed by clinicians. To ensure the successful implementation of the EMR system, at our field site, the design team even invited clinicians and department leads to what they called *Future Design Meetings* to demonstrate the systems being designed and to gather user feedback before the EMR was actually deployed in the field site. Nevertheless, such efforts do not guarantee a perfect system design and an adaptation phase still occurred after the system rollout.

Designing for such complex environments is extremely difficult, since designers often have limited knowledge about the work practices of clinical medicine, and clinicians' lack of design knowledge limits their input, even when they are included in design meetings. Thus, it is impossible to create systems perfectly matched to healthcare settings, and the design often needs to be adapted by users to fit with work practices.

Many studies have examined technological adaptation in the medical field. These studies mainly represent organizational, medical, and HCI perspectives [1, 4, 7,19, 24, 32]. However, these prior approaches did not explore how the adaptation process might inform design practices, and how users are involved in the adaption process, given the importance of technology use in the healthcare field and the significant consequences these systems may entail.

Therefore, in this study we intend to answer the following three research questions:

1) How EMR is adapted to the complex clinical work environment; 2) How clinicians engage and are involved in

the adaptation process, and 3) What we can learn from system adaptation to benefit the design of such systems.

We conducted a nine-month qualitative study examining the rollout of an EMR in an emergency department (ED) affiliated with a large teaching hospital. Our findings show that ED clinicians actively created various workarounds soon after the EMR deployment to adapt the system use. We describe three representative adaptation cases that illustrate clinicians' active involvement and design efforts during the adaptation period, as well as the workarounds used in documentation work. In this article, we consider adaptation period as an end-user design process, a negotiation process, and a re-routinized process. We also discuss the value of the adaptation for system design in the following aspects: end-users as invisible designers for redesigning their work practice, and the process of re-routinizing work practices after system deployment as a unique design time frame for forming new work routines. We also suggest designing a socio-technical system to encompass not only shared information systems but also the practices around all the artifacts, stakeholders, workflows, and physical layouts.

RELATED WORK

Although designers carefully create a product, system, or technology and expect it to fit its intended use and context perfectly, it always takes time for users to learn and adapt to the new technology [24]. Adaptation is defined as a process intended to modify the new technology or a related operating context, such as users' skills or procedures [33]. The adaptation process is considered a necessary stage after technological system rollout because it is extremely difficult to design a technology which perfectly fits the user environment immediately after deployment and also users do not necessarily participate in the original design process [24].

Technology adaptation plays a crucial role in shaping both individual and organizational behavior in different workplaces [15]. To understand the adaptation process, many prior organizational and social behavioral studies have constructed models for adaptation between technology and users - e.g. improvisational model, discontinuous patterns, and gradual reduction of misalignment [24, 27,33]. These studies propose various understandings of adaptation by examining it as a group knowledge sharing activity [10], as a mutual process between technology and its environment [24], and as a routine [11]. Nevertheless, these studies did not address the issue of why users engage in the adaptation process, or what motivates users to make efforts to adapt systems. Thus, they do not offer insight into how systems can be redesigned and how users can be involved in the design process.

As healthcare IT systems have been largely implemented in clinical work practices, the question of how to create systems which fit into these clinical work environments is considered very significant. Studies have examined many different technological systems in the medical field, such as EMR systems [1,7,12,19], a barcode medication administration system [23], a computerized medication dispensing system [2], and a computerized prescription order entry system [35]. Despite the benefits, such as easy access to patients records and better patient care quality [19], failures or unintended consequences have also been reported. These include increased documentation time [12,28], more interruptions [30], induced medical error [1,21], increased mortality [16], and incompatibility with clinical workflow [12]. Thus, systems designed for the healthcare environment are fraught with possibilities for error.

The complexity of the healthcare field has been widely noted by the HCI community. Much research has been conducted to examine crucial aspects in healthcare: these include, temporal coordination [29], spatiality [3], workflows [9], and communication breakdowns [29]. These works have revealed the problems in current healthcare system designs and call for more comprehensive work practices analysis in order to design systems for the complex medical work environment.

To cope with a new system's unintended consequences during adaptation, clinicians use various workarounds to adapt new work processes or bypass the new technology [2,23,32,35]. For example, nurses use workarounds, such as safety alert overrides and shortcuts to documentation, to minimize workflow disruption in electronic medication administration [34]. However, previous reports of workarounds in the medical context often consider them to be negative or unexpected consequences, neglecting the possible values of these user driven activities. Also, although most studies have focused on the nature of the workarounds, they seldom consider clinicians' motives for using workarounds or study workarounds to inform design.

To better understand clinicians' adaptation to EMR, we studied the rollout of an EMR in an emergency department. We present the process of clinician adaptation to the new system by describing three salient cases. Then, we utilize activity theory [20,26] and organizational routines [11,13] as theoretical frameworks to understand the potential use of these adaptation cases. Activity theory has been applied to a wide variety of settings in HCI research [20, 25]. Much of its use is derived from the prominent analytic place of tool mediation, where technologies are seen as tools mediating human activity. We attempt to define workarounds as mediating tools in the negotiating relations of clinicians and their EMR system use. We also utilize the concept of organizational routines to discuss adaptation processes because much of the work including workaround use in organizations is performed through routines. In this paper we argue that understanding clinicians' engagement in the adaptation process can provide useful insights for future system design processes.

ABOUT THE STUDY

This study was conducted in an ED affiliated with a teaching hospital. At our field site, a large-scale, comprehensive EMR system was implemented. The EMR was custom-designed locally for our field site and has been used in the hospital for about a year. During the first three months of our study, all documentation work was paper-based, until the paper system was replaced by the EMR system after a week-long transition stage. Our field observations were then carried out for another six months after the EMR deployment. This timing afforded us unique opportunities to observe nuanced adoption and adaptation behaviors and to understand the impact on the system of the paper-to-electronic notes transition—an impact which was difficult to trace in other retrospective or cross-sectional studies [12,16,28].

After the deployment, all ED clinicians utilize the EMR system to perform medical tasks. Doctors use EMR for tasks such as the documentation of patient records, ordering, and the admission and discharge process; triage nurses also document their assessment notes in the EMR; bedside nurses use EMR for order-related tasks, but they still use paper-based documents, such as patients' flowsheets and nursing notes.

METHODOLOGY

Setting

The main goal of ED care is to promptly stabilize patients' medical problems and make decisions either to admit or to discharge patients. The ED is divided into five areas: triage, ED1, ED2, ED3, and the doctors' charting room. In triage, triage nurses conduct a brief initial assessment of a patient's condition and quickly determine its urgency before handing the patient off to an assigned ED nurse. Each ED unit is differentiated based on the severity of patients' illnesses. Lastly, the doctors' charting room is located at the center of the ED and is a closed, separate space. It is noteworthy that the charting room is placed between ED1 and ED2, allowing doctors to check more severely ill patients often and conveniently. ED3 is located the furthest from ED1 and the charting room, since ED3 patients are more stable than those in ED1 and ED2, and less likely to experience emergencies [Figure 1].

Figure 1. A map of the main ED area

Data and data collection

We utilized qualitative field study methods in studying the deployment of EMR. Our observation entailed following the clinical documentation process in key locations: the patient waiting room, front desk, triage, nursing stations, doctors' charting room, patient rooms, and other public areas in the ED. Two researchers stayed in one location to observe the main activities of the ED staff at each location and the ways different artifacts such as paper charts and the electronic system were used to support these activities. We also followed key personnel and artifacts in our observations, such as patients' paper charts and admission and discharge processes, to comprehend the general ED workflow from various perspectives.

Our observations totaled 210 hours over a period of 9 months. Each observation session lasted approximately 4-5 hours. They were distributed across different time periods, from early mornings to late evenings, on weekdays and weekends. The ED staff we studied included 12 residents, 9 attending physicians, 3 charge nurses, 15 registered nurses, 2 float nurses, 2 front desk clerks, and 1 hospital unit service coordinator. We also interviewed 8 doctors and 15 nurses in order to gather clinicians' perceptions and opinions on EMR implementation and related issues, such as workarounds, that emerged during EMR use.

After observations and interviews, we analyzed collected data using various diagramming methods including affinity diagrams, communication diagrams and flow diagrams [5]. Workflow and communication flow diagrams helped us understand where and how the EMR system was used in their documentation work process, and why individuals have different perceptions of it. Open coding [14] was used to look for recurring themes in the data on clinicians' documentation work process before and after the EMR rollout. In particular, we analyzed the perceived workflow before, after, and during the EMR deployment from the perspective of tool mediation in activity theory [20,26]. This approach afforded us a unique perspective on "tools as mediators" and helped elucidate how the tool change from paper to EMR affected clinicians' pursuit of the goals of documentation work in different medical activities and contexts.

ADAPTATION OF THE EMR SYSTEM DEPLOYMENT

The EMR system brought changes but also challenges to the ED work practices. The challenges of using the system forced clinicians to develop several workarounds to help their work practices fit the new system. In their adapting process, we identified three salient adaptation cases to show different workarounds developed by doctors and nurses: (1) use of tailored questions as new computer-interaction mechanism, (2) use of personal notes as new documentation artifact, and (3) use of a centralized printer as reconfigured physical environment. These workarounds illustrate the ways in which ED clinicians became actively engaged in the adaptation process.

Adaptation Case 1: New Interacting Mechanisms in Using the EMR

Compared to paper triage charts, the newly-deployed electronic triage note dramatically increased the triage charting time in the ED. In order to cut down the increased triaging time, nurses started utilizing tailored questions, instead of the entire questions displayed on the EMR system, as a new workaround for each individual patient case. This new workaround helped them reduce the lengthy triage charting time induced by the design of the new system. By engaging in this tailoring process, nurses found a new way of interacting with the system adapted the system to fit their work practices.

Most ED patients (apart from Advanced Life Support (ALS) patients) go through ED triage when they first arrive in the ED. The goal of triage is to conduct initial medical assessment and quickly decide which ED unit the patient should be admitted to. To do so, triage nurses gather necessary information from the patient, and document this as triage notes, which are then shared with ED doctors and bedside nurses.

Figure 2. Newly deployed electronic triage notes

Before the EMR system was introduced, triage nurses performed initial patient assessments using a paper copy of the Medical Screening Exam (MSE). They often checked vital signs, asked about Chief Complaints (CC), and recorded the answers to relevant questions on topics such as medical history, allergies, or medications. The paper MSE contains only the key issues that are critical in the triage process; other than CC and medical history, most of the questions can be documented in simple check boxes. Thus, it usually takes only 5-7 minutes for triage nurses to finish the entire triage task.

After the EMR deployment, during the first month of the EMR use, triage nurses complained fiercely about how slow it was to chart in the EMR system. Compared to the paper MSE, the electronic MSE requires more concrete notes as well as more questions for each medical issue. For example, if a patient is a smoker, the electronic MSE requires details on how often he smokes, and whether it is daily, weekly, monthly, or yearly. Although more information is assumed to be better in terms of patient care, asking such details should not be the main purpose of the quick triage process. In addition, input in the electronic MSE can only be in one format. For instance, if a nurse wants to enter the name of a specific allergy or medication, she has to scroll through all the names in the long medication list and select the one she wants, instead of typing it in. With this detail-driven documentation, triage time expanded to 10-15 minutes after EMR deployment. As a result, triage became a bottleneck for patient flow, disrupting the quick turn-around of ED practices [Figure 2].

To cope with this problem, triage nurses started tailoring triage questions in order to shorten the time spent on the electronic triage documentation process. Now, to make their work smoother, nurses ask only questions relevant for their decision-making, instead of all the questions in the electronic MSE. This new interaction mechanism shortened the triage time back to 5-7 minutes and removed the triage bottleneck in ED patient flow.

During the interviews, one triage nurse commented on the adapted triage practice:

> *[Sara] It's just learning – you have to learn the flow of the form in the computer… Before, it took a while, I think just because we weren't familiar with the form and the flow. But now we ask necessary questions… we're familiar with the form and the flow, it's easier.*

As the quote indicated, Sara considered the new way of interacting with the system a better way of using the EMR and applauded the new adaptation, since it helped them work more efficiently. Therefore, this new workaround developed by triage nurses provided a new way of interacting with the EMR, different from the way EMR use was originally designed.

Adaptation Case 2: New Artifacts to Leverage EMR-based Documentation

After the EMR implementation, ED doctors found EMR-based documentation could not support bedside documentation as paper charts did. It required doctors to recall the information gathered at bedside to document it in the charting room; in other words, it required intensive *memory work*. Because of this, ED doctors began using personal notes use to help them retain and carry bedside information. The use of personal notes was an adapting process for ED doctors, demonstrating new ways to document in order to leverage the difficulties in electronic documentation.

Previously, ED doctors were able to perform most of their charting work at the patients' bedside. The paper charts were designed to record a brief medical history, diagnosis, medical decision-making, and vital signs. They were simple and intended to be carried by doctors as they moved around the ED. Doctors would enter the patient rooms with the charts and fill them out as they talked to the patients and caregivers. Thus, by the time they were out of the room, their paper charting work was mostly finished.

After the EMR rollout, ED doctors were no longer able to conduct the bulk of their initial documentation at bedside.

As EMR completely replaced paper charts, doctors were required to conduct charting tasks exclusively on the computer; they could no longer take these records with them and read the records as they moved around. To work with this new documentation practice, ED doctors had to rely purely on memory to retain patients' medical information before it could be documented outside the patient rooms. It soon became obvious that it would be difficult to remember all the relevant patient information, since the EMR actually requires much more detailed and more specific information than the paper charts [12,28]. Moreover, when ED doctors had to see multiple patients in a row at busy times, the play-by-memory mechanism then led to a large backlog of information for multiple patients - a problem that has been reported in prior studies [9,17].

This problem continued to exist even after wall-mounted computers were installed in patient rooms and computers-on-wheels (COW) were used in the ED, because typing out all the required information was too time-consuming. In addition, most doctors preferred to have natural, face-to-face interaction with patients, rather than attempting to interact while looking at a computer screen and typing. We noticed that in many cases, the computers were mounted on the walls at bedsides or in patients rooms in such a position that the computer's user would have to turn away from the patient. Because of this, the ED doctors felt they could not document electronically at patients' bedsides even when bedside computers were available.

To alleviate the amount of memory work, a few doctors developed a workaround - the use of paper notes - to record and transfer bedside information to their office. Later, this workaround became common practice for all ED doctors. Some doctors printed out a triage note from the EMR system before they went to see a new patient; others utilized blank papers. Doctors found that the use of triage hardcopies of personal notes was particularly helpful in transferring information from the doctors' room to new patient rooms, since they read the patient's record shortly before meeting the patient. Thus, by using paper notes, they were able to save time, previewing the records as they walked the hallways.

Doctors actively developed different customized strategies in using the personal notes as they sought ways to adjust to the new electronic charting process [Figure 3]. Before or during the consultation, doctors jotted down memos: some compiled a set of questions in their paper notes, which replicated the structure of the formerly used paper charts; others even drew separate tables on their paper notes to organize multiple patients' information and keep an eye on multiple patients' situations simultaneously. Doctors usually kept the notes until their shifts ended so they could then complete all the documentations.

One attending explained the rationale of his personal note usage during the interview:

> *[Attending – Steven] I just need to know what the patient name is and what's (inaudible) and what's their chief complaints. So – and who's taking care of them. I need to know those four pieces of information at all times and we don't have a good way of doing that right now. So, I need to be able to – I need a better system of all of that is to have it on my Palm and as I'm walking around my patient list is right there and I can see all of that. But that's not available.*

This quote points out ED doctors' need for a portable, recordable artifact to fill the gap between the existing workflow, that needs to be mobile, and the new electronic charting, that only supports stationary work. Similar observations have been reported in the other work of transitional artifacts [9].

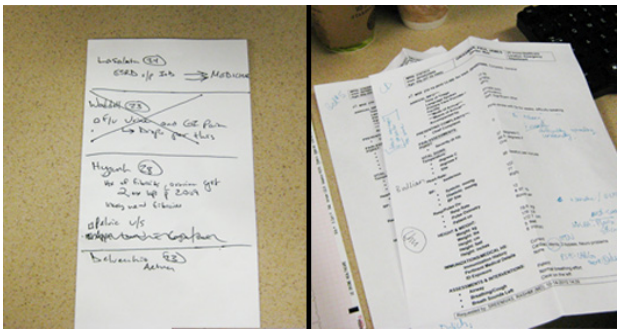

Figure 3. Customized ED doctors' personal notes (Left: notes on empty paper, Right: notes on triage copies)

In summary, personal notes are a workaround created to adapt to the new EMR system uses. This adaptation helped ED doctors to perform documentation work more efficiently, and reduced the amount of memory work. In this instance of adaptation clinicians interacted with the system differently, but also actively created new solutions beyond the current system use. In this case, the paper notes were developed as a new documentation tool. Combined with the EMR system, they become the new documentation system in the ED in order to support effective bedside documentation.

Adaptation Case 3: Reconfigured Physical Environment to Facilitate EMR Use

ED clinicians did not only change the way they interacted with the EMR and create new artifacts to extend EMR use; they also reconfigured the physical environment to adapt and facilitate EMR system use. One representative case was the redesign of the printing system on the ED floor for printing transmittals. Transmittals are paper copies of lab orders from the computerized order system. Transmittals must be sent with each lab sample in order to verify the status of the order. Thus, clinicians need to print out transmittals and send them along with specimens to the lab department whenever they put in lab orders. Nevertheless, the new EMR system limited ED doctors' use of printers for security reasons: it only allowed them to print from a

printer connected to the computer they first logged in on. To resolve this problem, clinicians changed the printer system to improve accessibility based on the physical layout of ED. This new workaround --reconfiguring the physical work environment--helped clinicians use the printer conveniently and divide their responsibilities efficiently in managing transmittals.

Before EMR deployment, it was mainly doctors' responsibility to order documents and deliver them to nurses: a doctor wrote a lab order in a paper order sheet, put it into the order system, printed out a transmittal, and brought all these papers together to the shelf at a nursing station, so the nurse could receive and administer this order. Doctors often used computers and printers at the nursing stations for this work, because they could pick up the printed transmittals immediately after seeing patients and drop orders off with the nurses. Moreover, since paper charts including order sheets had to be kept in the shelves at nursing stations during a patient's stay, it was more convenient for doctors to write an order on a paper order sheet, put it into the computer, print out a transmittal from the printers, and directly hand transmittals to the nurse – doctors were able to do all ordering tasks at the nursing stations by using any available computer.

In contrast, after the EMR system was implemented, doctors were no longer able to print the transmittals conveniently from any printer at the nursing stations. They could print orders only from the printer connected to the particular computer that they originally used to log into the system. Thus, with EMR, doctors were required to log off completely after use if they want to use other computers for printing. Although they could log into another computer, remaining logged-in on both computers, only the printer connected to the first logged-in computer could perform the printing job. Due this change, they were required to make sure to log off the computer after use, or remember which computer they first logged in (if they forgot to log off previous one) so that they would know where the transmittals were printing.

This design posed a problem for ED doctors. Although ED doctors were supposed to log out of their computers after every use for the sake of protecting patient privacy, due to various emergencies such as calls from acute life support (ALS) patients, doctors often forgot to log off from the computers they were using. In addition, they preferred to use whichever computers were close to them to input orders, instead of returning wherever they logged in previously. During the observations we saw many doctors trying to use computers at the nursing stations and giving up on putting orders into the system after realizing that they could not print out transmittals from there. One resident expressed his frustration that his workflow was altered by EMR, requiring him to figure out which printer he could use or should be using:

> *[Resident – Andrew] That is very annoying because you have to give that [transmittal] to the nurse. And sometimes we don't know what printer it's going to… We hate that. Especially in the ED3. You print something and then you write your orders and then you have to find out where these printouts came out of. So it's just busy work that takes care away from your patients, which sucks.*

To address the doctors' difficulty in locating the printout for each transmittal, the ED department leadership decided to shift all transmittals printing work to nurses and made the printer in ED1 the sole centralized place to print out all ED transmittals. This change allowed doctors to use any computer for orders, but required nurses to pick up transmittals only from the ED1 printer. Now, doctors enter orders into the system via any computer terminal and nurses pro-actively consult the system to check doctors' orders, then print and pick up transmittals.

In this case, the inconvenience of having to search for printouts forced ED administrators to develop a new workaround by reconfiguring the physical environment (this was a collective workaround that individual clinicians could not implement). Since the EMR system itself could not be reconfigured to fulfill this need, clinicians redesigned their working environment to accommodate the design of the EMR system. To resolve the breakdown in work practices caused by EMR, they adapted a new documentation system for orders encompassing the reconfigured ED physical layout, ED printers, and EMR.

DISCUSSION

In this section, we first discuss the adaptation process from the perspective of the user design process. Then, we use the theoretical framework of "activity theory" to better understand workaround creation around ED documentation work. Finally, we discuss the temporal structure of adaptation processes using re-routinized processes.

Adaptation as an End-User Design Process

In our study, ED clinicians adapted to the new EMR system by creating several workarounds. This can be viewed as a process of redesigning computer systems and work practices through doctors' own active engagement. When the EMR deployment created problems in clinician's work practice, they made efforts to fix these issues by creating workarounds. In the process of developing workarounds, ED doctors and nurses transformed their role: from *users* of the EMR system, they became *designers* engaged in the design of the socio-technical system through the process of adapting and improving the original EMR design.

In fact, adaptation is a critical process in designing socio-technical systems in medical practice. Since healthcare is a highly complex field with an extremely dynamic working environment, a good system design requires not only knowledge of HCI but also sufficient understanding of clinicians' work practices [3,9,29]. This is often referred to

as *symmetry of ignorance* [28] in the HCI field: designers and clinicians lack knowledge of each other's specialized domain, and are therefore unable to communicate effectively and understand each other. The gulf between designers and end-users is even wider in the case of a complex domain, such as clinical practices. Thus, even when clinicians are invited into the design process, they may not be able to recognize and articulate potential problems. Because of this, the final adaptation stage after system deployment is inevitable and system designers will benefit if they can learn from the adaptation process. As was evident in our study, clinicians were forced to participate in redesigning activities and solving problems during the adaptation period, since no designer would know enough about their work practices to help them adapt the system use. The adaptation of new system requires ED clinicians to go beyond being passively learning to use the technology as end-users, and puts them in a position to actively consider and create new workaround systems—a position which is essentially a design position.

Adaptation of system use is usually examined as a "deployment study" or as "system evaluation" [18,35] In contrast, in this study we consider adaptation as an end-user design process, where end-users participate in creating new uses, tools and contexts to perfect the working system. *Design* and *evaluation* are closely related [18], yet typically separated in practice. Although they share a common goal, the evaluation community primarily emphasizes the evaluation of designed artifacts, whereas the design community focuses primarily on the design of artifacts that will be evaluated afterwards. From this conventional standpoint, the ED clinicians' adaptation stage described in our study may be regarded as an *evaluation* of the system. However, we consider it to be the *design* of a socio-technical system. Clinicians do not simply reveal deficiencies in the systems; they also create new usages, new tools and new work practice in the process of adapting to new system. From this perspective, design does not end at the moment of system rollout; rather, it is extended to the point where the adaptation process happens and includes user engagement. Therefore, lack of understanding of this end-user design process during adaptation period would lead to design efforts being left out – new artifact creation, different artifact use, or technology and user environment reconfiguration would not be recognized and incorporated in the next iteration of design.

Adaptation as a Negotiation Process

We described the ways in which each clinical group became actively involved in workarounds as they adapted to the new EMR system. The workarounds included tailored questions use, personal notes use, and reconfiguration of the physical environment. In creating these workarounds, clinicians had to find ways to overcome the problems caused by the use of the EMR – a process of n*egotiating* with the system, artifacts, physical environment, and work practice itself for the purpose of getting work done. The term *negotiation* has been adopted from activity theory (AT). In AT, negotiation has been depicted as a natural way of engaging tool use. AT describes all human activity as mediated by tools (also referred to as artifacts; e.g., instruments, signs, procedures, methods, forms of work organization)[20,26]. An activity is performed by a subject (an intentional agent), directed towards a specific object, and mediated by the tools. In AT the relationship between subject and object is mediated by tools and the process of using tools can be viewed as a negotiation process. In our study, the tool previously used by ED clinicians for the purpose of documenting patient records and orders was the paper chart. After EMR deployment, the entire system was expected to replace paper charts and become the new documentation tool. However, the flaws of the new tool forced clinicians to negotiate the available resources and create new tools to support their goal of working efficiently and effectively.

In this negotiation process, doctors and nurses negotiated different tools, such as the system, other artifacts, and the physical environment, to achieve their work goals. In particular, triage nurses negotiated the electronic triage note by tailoring sets of questions to reduce triage time; the doctors negotiated the EMR use by extending the documentation system to include paper personal notes; and finally, when the system impacted the work practices in the entire department, the department leadership made collective changes by adapting and setting up new policies to benefit the entire ED, allowing doctors to expedite collaborative work for lab orders.

Activity theory describes tools as a mediation artifact linking relationship between subject and objects. In our case, the subjects and objects of work remain the same before and after the EMR deployment. When a newly deployed tool is not able to meet clinicians' needs, clinicians negotiate and redesign new tools in the course of their adaptation process, instead of using the deployed tool as it is. Clinicians' use of new tools extends the EMR system itself by modifying the system, and these modifications include other uses of new artifacts and changes in policies to make clinicians' work practices more effective. Our analysis suggests the importance of looking beyond the computer system itself when studying adaptation processes for socio-technical systems. In our case, tools are even extended to encompass new artifacts and new printing system. These tools are part of the working system that mediates between clinicians and their work goals. However, these tools which exceed the bounds of computer systems are not always recognized and incorporated in the system design process.

Adaptation as a Re-routinized Process

In adapting to the new EMR system, clinicians developed several different workarounds. A workaround starts with creative attempts to find ways to work more effectively and efficiently, but once it meets their needs and is used

continuously, it is eventually formalized as part of the work *routine* – e.g. the case of the personal notes which became a part of doctors' documentation workflow. Routines within organizations are defined as repetitive, recognizable patterns of interdependent actions carried out by multiple actors [13]. The adaptation process develops, refines, and formalizes workarounds into existing work practices, and can be considered a routine-forming process.

In the adaptation period, the routine-forming process starts by breaking with previous routine. When EMR entered the clinicians' workplace, it disrupted the balance of clinicians' previous (*un-routinized*) work; consequently, they strove to piece together new routines (*re-routinized)* by rethinking and reinterpreting their previous practices and work settings. Anticipation of new work methods and lack of familiarity with the new system made ED doctors' busy routine unfamiliar to them. They were also pressured to re-think how work had been conducted previously, before the EMR, and how it should be done in the future. For example, in the case of new electronic charting, doctors realized the new system did not support bedside documentation—indeed, it disrupted documentation in general. As a result, they had to analyze the gaps EMR created in their workflows, and had to question the rationale behind the previous work practice with paper records. (For instance, they had to question why it was important to face patients, or to be seen writing on paper, in the context of bedside work.) They then started designing a new, extended documentation tool by using personal notes. As can be seen from Sharam's interview statement, in order to maintain his documentation work after it became apparent EMR did not support his mobile workflow, he had to think of ways to carry around the information he needed. Thus, using the EMR system caused him to acquire a new understanding of his existing work routines. Thus, as clinicians in the adaptation stage try to fix the breakdowns in routine while working with the new documentation tool, this process reconstructs new routines in their work.

In the course of regaining routines, doctors and nurses went through multiple iterations of developing and refining workarounds. When they began to use the workarounds, they redesigned them several times to better support their tasks: the doctors tried out several ways of organizing their memos on the personal notes, the triage nurses refined different ways of tailoring questions on electronic triage notes, and clinicians modified their use of printers by varying physical locations. Less successful workarounds might simply disappear during the process. Also, in addition to multiple iterations within a single workaround, an existing workaround could even produce the need for a new one—to cope with new problems caused by the current workaround use. Thus, when doctors designed the workaround consisting of using one centralized printer in ED1 for all transmittals, they realized that they sometimes forgot to pick them up in a timely manner, so that many transmittals were left sitting at the ED1 printer. To address this, doctors developed another workaround: they handed over responsibility for transmittals to nurses. This evidence shows that the adaptation process can comprise several rounds of workaround development rather than a single one. After going through these iterations, workarounds are adapted by the practice as new routines.

Thus, the re-routinizing process has an internal temporal structure. It emerges as a way of accomplishing organizational work over the course of the adaptation to the new practice. When a new technology intervenes and causes old routines to break down, people try to reconstruct new ones by developing workarounds. This process can be seen as gradual effortful accomplishment throughout the course of the adaptation period [13]. As people adjust to the new practice, they act, reflect on the result of these actions, and modify their routines accordingly. In our case, EMR deployment was simply an artifact that enabled creation of new routines, rather than dictating routines. It also enabled people to reflect on their actions constantly until they were finalized and stabilized as new routines. After this re-routinizing stage, people will use adapted workarounds naturally, without even having a conscious rationale for using them. We observed new incoming residents immediately picking up and utilizing the practice of personal notes as if it were a norm of ED doctors' workflow. Our study shows the value of recognizing the re-routinizing process, since this process can provide a unique perspective for understanding the design rationales and design decisions subtending user-driven design activities.

DESIGN OPPORTUNITIES

Based on our analysis of ED medical work practice after EMR deployment, we contend that the adaptation process comprises a significant design component. This new perspective can benefit the field of HCI, since prior literatures often argue that use of workarounds (adaptation process) emerges from problems in system design, and view them as negative consequences of the deployment [2,23,32,35]. In contrast, our findings suggest that adaptation is an end-user design process and highlight the importance of understanding the socio-technical systems and design rationales behind these design activities.

Clinicians' active involvement in developing workarounds illustrates clearly the value of an end-user-driven design process. Although most previous works have considered workarounds to be negative results [21,34,35] or subsume them in the process of evaluation of the system [21], they have focused mainly on workarounds themselves rather than studying how these workaround are developed and why they are developed.

This paper shows that workarounds were the result of active design efforts; clinicians participated in the design and strove to make the new system work in the ED. It is worth mentioning that end-users in our field site were invited to various "future design meetings" before the system deployment. Clinicians saw demonstrations of design

prototypes and were asked for feedback, but *symmetry of ignorance* interfered-- lack of design knowledge made it difficult for them to engage in design meetings. Nevertheless, when clinicians' work practices were impacted by the system, they automatically became invisible designers and worked to redesign system use during the adaptation period. This finding reveals new opportunities to engage end-users in the design process. In designing complex working systems, conventional approaches, such as the participatory design method, might not be effective. This is because participatory design tends to only occur at the early stage of the design process, instead of being used for other later stage design activities. More recent discussions on participatory design has recognized the challenges and benefits of moving toward a sustained long-term design process in product development, (e.g., user-driven design, design in-use [6, 8]). Hence, we think the end-users' role in the adaptation process is actually an active type of participatory design. Furthermore, we argue the invisible design work performed through system adaptation stage by end-users can offer valuable insights to the design community, and this active design activity should be captured to inform design practices for similar complex working environments.

One of the prominent observations from the study was that the workarounds initiated by clinicians were primarily used to accommodate the complexity of ED work practice in the socio-technical system. As they negotiated tools in work practices, ED clinicians used a system which extended beyond the computer system itself and incorporated many physical and contextual artifacts interfacing with the EMR system. This negotiation process can also be viewed as an interaction between the system and local practices - work practices, physical layout and workflows unique to our field site. Although general medical practices may be similar and EMR design can meet these goals, local factors such as patient volume, mobile workflows, accessibility of printers, or physical layout of each ED unit all interact and affect the use the EMR system. This adaptation into local practices is critical yet it was insufficiently considered in the original design. Therefore, we suggest that design practices envision ED as a complex, socio-technical system that encompasses the practices surrounding all the artifacts, stakeholders, types of patient care, spatial layout, existing technological use, and the clinical workflow of the local site, as well as shared information systems.

Last, we suggest that design practice exploit the transitional period to analyze clinical work routines and end-user design routines. This study covered the previous paper chart documentation, EMR-based documentation, and the stage when the work practice transitioned from paper to electronic practice. Comparing these three stages in our observations, we discovered that the transitional stage, in particular, enabled clinicians to gain a better understanding of their own work process, re-recognize their work settings, and engage in redesign of their work practices. Breaking down routine work then gradually regaining a sense of familiarity allowed clinicians to express their concerns about the design and articulate rationales for their redesign efforts. Once work is routinized after this transition stage, fresh reflections on the system use and redesign are likely to be lost. Thus, we suggest that designers should value the transitional period, namely the un-routinized phase, as part of the design process--and gain design insights from close examination of the transitional period, especially users' active adaptation stage, after system deployment.

CONCLUSION

In this paper, we investigated ED clinicians' process of adaptation to the newly deployed EMR system in their work practice – how EMR is adapted to the complex clinical work environment and how doctors and nurses engage and are implicated in the adaptation process. We specifically focused on the detailed design processes ED clinicians used to create workarounds to adapt to the new work practice. Our study uncovered the ways ED clinicians actively reinterpreted and modified their work practice through their engagement with the system-in-use and its organizational and physical context. We then analyzed doctors' and nurses' adaptation process by utilizing theoretical concepts of tool mediation and the notion of organizational routines. These findings suggest that when designing a socio-technical system in healthcare settings, one should consider the significance of the adaptation period as an active design process by end-users, as a negotiating process, and as a re-routinizing process.

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