The Situated Nature of Adaptive Learning in Organizations

Marcie J. Tyre • Eric von Hippel
Massachusetts Institute of Technology, Sloan School of Management, 50 *Memorial Drive, Cambridge, Massachusetts* 02142

Abstract

This paper explores the nature of adaptive learning around new technology in organizations. To understand this issue, we examine the process of problem solving involving new production equipment during early factory use. We find that adaptation is a situated process, in that different organizational settings (1) contain different kinds of clues about the underlying issues, (2) offer different resources for generating and analyzing information, and (3) evoke different assumptions on the part of problem solvers. Consequently, actors frequently must move in an alternating fashion between different organizational settings before they can identify the causal underpinnings of a problem and develop a suitable solution.

These findings suggest that traditional, decontextualized theories of adaptive learning and of collaboration could be improved by taking into account that learning occurs through people interacting *in context*—or, more specifically, in multiple contexts. Learning is often enhanced not just by bringing people together, but by moving them around to confront different sorts of clues, gather different kinds of data, use different kinds of tools, and experience different pressures relevant to a given problem. We discuss both managerial and theoretical implications of these findings.

(*Situated Learning*; *Learning by Doing*; *Adaptive Learning*; *Technical Problem Solving*)

Introduction

Problems encountered in the process of trying new policies, technologies, or behaviors are a major source of learning and improvement in organizations. As Hedberg (1981, p. 4) argues, "attempts to act expose the conditions for acting; causal relations . . . are gradually untangled." However, despite its importance, we have only a partial understanding of the adaptive learning processes underlying such "untangling."

This paper uses a situated theory of learning to examine how organizational actors use physical context to confront problems and to develop the new understanding needed to deal with them. This perspective differs from behavioral theories of learning that pay attention to whether or when adaptive learning occurs (e.g., March and Simon 1958, Cyert and March 1963, Levitt and March 1988), or cognitive theories that focus on the kind of understanding that results from learning processes (e.g., Argyris and Schon 1978). Specifically, a situated learning framework directs attention to the particulars of what problem solvers actually do as they investigate problems and correct errors, and how they use the resources available to them in this process. Thus the use of a situated perspective enables us to highlight the role of the physical setting in adaptive learning. It suggests that learners' physical context, although often overlooked as a mundane detail, is in fact a critical and poorly understood component of adaptive learning processes in organizations. Further, this perspective has important implications for organizational design and problem solving behavior that merit attention from both practitioners and theorists.

Background

A situated theory of learning has its roots in the pragmatists' notion that knowledge is not absolute, but rather can only be defined in relation to a specific situation or context (Dewey 1938, James 1963). Questions about what is "true" are answered in relation to what works in a given setting. For example, as Knorr-Cetina (1981) and Latour and Woolgar (1979) have shown, cultural norms and social practices often determine which ideas become accepted as "facts."

A related school of thought challenges traditional thinking about the very forms that "knowledge" can take. Theorists with a pragmatic view (e.g., Ryle 1949, Bordieu 1977, Giddens 1984, Lave 1988) argue that knowledge does not consist only of verbal (or written) explanations and directions, but also includes the ability to get things done. Thus, an actor is "knowledgeable" to the extent that he can act intelligently, even if he lacks the ability to describe the actions involved.

1047-7039/97/0801/0071/$01.25

Perhaps the most well-known formulation of this view is Polanyi's (1958) notion of "tacit" knowledge. However, Polanyi's ideas have often been used to draw a sharp distinction between codified knowledge and tacit capabilities. By contrast, research on situated learning reveals that intelligent actors incorporate codified, abstract theory into local, informal routines, freely adapting it as they work on actual problems in their particular social and physical circumstances. Thus, intelligent or knowledgeable action draws on both the actor's intellectual understanding and her ability to "use [the] material and social circumstances" available in a given context (Suchman 1987, p. 50).

This works in several ways. First, each setting presents a particular mix of resources, (such as people, tools, and events) that can be used to help solve a problem in non-codified ways. For example, while a secretary who needs to use half a sheet of typing paper might be aware that there is a formula for dividing any rectangle into equal halves, she is likely to do this simply by aligning the corners of the paper and folding it. Further, the way in which such resources are used will vary with the particular setting, since "the significance of artifacts and actions, and the methods by which significance is conveyed, have an essential relation to their particular, concrete circumstances" (Lave 1988, p. 171). Thus, Lave points out that people will approach a problem differently when they act in different settings (e.g., in school vs. at home, on an exam vs. in a game) because each setting tends to evoke certain kinds of "appropriate" modes of thought and action.

Moreover, problem solvers often use the setting itself to help them define a problem or to discover solution paths. As Lave (1988, p. 169) suggests, "the person-acting and settings, in activity, together generate dilemmas and resolution shapes." An example of this comes from Alexander's (1964) discussion of design practices among "primitive" peoples, whose everyday living in and around their huts constantly reveals new housing design problems to be resolved, and simultaneously suggests ways to resolve those problems. Similarly, Hutchins' (1990) description of shipboard problem solving shows how the problem takes its form from the kind of tools available in a given setting. As he describes, "each tool presents the tasks to the user as a different sort of cognitive problem requiring a different set of cognitive abilities or a different organization of the same abilities" (Hutchins 1990, p. 205).

Situated theories of learning have important implications for how learning and problem solving take place in organizations. First, this perspective suggests that abstract theories cannot completely account for learning in organizations. Rather, because learning is a social process, the social and cultural context will affect both how and what organizational actors learn. Second, a situated perspective suggests that the learning process will also depend on the physical setting in which actors find themselves, because problem solvers make use of many aspects of their physical contexts in order to understand new problems and to resolve them.

The first of these insights has received far more attention than has the latter. It is now well accepted that learning in organizations is frequently an interactive, social phenomenon. Almost 20 years ago, March and Olsen (1975, p. 166) noted the importance of "processes like discussion and persuasion, and ... [of] relationships like trust and antagonism" for making sense of confusing, ambiguous events in organizations. More recently, such communal processes have been widely studied; they are variously described in terms of social sensemaking (Weick 1979), storytelling (Orr 1990, Brown and Duguid 1991), collaborative inquiry (Argyris and Schon 1978), collaborative diagnosis (Cicourel 1990), inter-entity knowledge relationships (Ching et al. 1992), and confrontation and contest (Cicourel 1990, p. 139).

Collaborative processes are important because no one person embodies the breadth and depth of knowledge necessary to comprehend complex organizational problems, and also because codified, abstract "knowledge" is seldom sufficient to deal with actual problems in organizations. For example, Orr (1990) and Brown and Duguid (1991) argue that, in the context of machine repair technicians, knowledge does not come from what is taught in the classroom, but rather from informal story-swapping among technicians and users about their experiences in particular work environments. Similarly, Nonaka (1994, p. 22) argues that "social interaction among individuals, groups and organizations are fundamental to organizational knowledge creation," because such interaction helps put problem solvers in touch with the actual problems that arise in the use of their products or policies.

By contrast, the role of the physical setting has not received nearly the same attention in the organizational learning literature as has the need for human interaction. When theorists do discuss place, they tend to refer to social space rather than to actual physical places. For example, Weick and Roberts (1993, p. 358) suggest that collective, organizational memory is possible because organizational actors "know the locations rather than the details of common events." Interestingly, the term "locations" here refers to the people who have knowledge of these events, not to physical locations. Similarly, Nonaka (1994, p. 23) suggests that teams provide a "field" or "place in which individual perspectives are articulated, and conflicts are resolved..."

To the extent that location has been discussed, the focus has been on the physical distance between actors and its effects on interpersonal communication. Ever since Allen (1977) demonstrated the strong effect of office proximity on information exchange among R & D personnel, the importance of "co-location" of colleagues or project team members has become increasingly widely accepted. More recently, other researchers (e.g., Oldham et al. 1991, Pentland 1992) have highlighted the impact of more subtle aspects of the physical context, such as the use of private offices vs. office partitions, on problem solving communication within an organization. Even when authors have argued that knowledge about a given phenomenon (e.g., technology) comes from experience in the context of use, they have not explicitly discussed the difference between direct, on-site experience and interaction with experienced users (e.g., Leonard-Barton 1988, Brown and Duguid 1991). Thus, while we know that communication among users and others is often critical for organizational problem solving and learning, we do not know whether it matters *where* these activities take place.

In this paper, we start from the insight that physical setting plays an important, constitutive role in problem solving or investigative activities. We note, for example, that marketing analysts visit field sites, potential buyers travel to manufacturers' showrooms, and engineers often go to customer locations to investigate complaints. Similarly, technical experts frequently move from their normal workplace (a development lab) to the factory or other field site to deal with technical problems (e.g., Tyre and Hauptman 1992). However, existing research has not examined why these shifts in physical location are so important. Thus, we examine why such shifts take place, and how organizational actors use their physical settings to learn about and resolve problems.

We find that the physical setting contributes to the learning process in several ways. The events, procedures, technical systems, and daily routines embedded in a given setting provide learners with both specific clues as to the nature of the problem (or solution), and tools or resources to aid investigation. Thus, *where* activities take place partly determines what actors can do, what they know, and what they can learn. It not only determines who can interact directly with whom, but also the way in which interactions unfold.

Moreover, because different settings provide different opportunities for learning, activities in different physical settings have a cumulative quality: progress in one setting often makes it possible to use clues or resources found in a different physical domain. Thus, learners often have to shift repeatedly between several settings (e.g., lab and plant) before they can reach an understanding of the underlying problem and develop possible solutions.

We argue that if adaptive learning in organizations is a situated process, then the physical settings of such learning deserve greater attention from scholars and managers. People's usable skills often depend on their physical settings because people act skillfully by using specific machines or tools, by interpreting physical cues, by exploiting their intimate knowledge of local idiosyncrasies, and by responding to stimuli embedded in a specific context. Seeing, touching, and manipulating are obviously important avenues for improving understanding, just as hearing and explaining are; yet, they are nearly overlooked in the organizational literature on adaptive learning.[1]

This perspective suggests that traditional, decontextualized theories of collaboration could be improved by taking into account that learning occurs not simply through human interaction, but through people interacting within one or more particular physical contexts. This insight, in turn, calls into question certain aspects of the received management wisdom. For example, it may be that recommendations to co-locate a team by bringing participants together in one place are incomplete because they focus only on the need for togetherness, while ignoring the location where interaction occurs. Further, efforts to erase spatial distinctions among team members may impose unexpected costs. Given that complex organizations *are* spatially distributed, and that physical setting is important to the learning process, managers might be wise to instead *exploit* these spatial differences for their learning potential. Managers might do this by moving key actors across spatial barriers within the organization to confront various aspects of a problem, or to search for creative solutions. This issue is discussed further in the last section of the paper.

Methodology

Research Setting

Data for this study were gathered from two projects involving the introduction of new production machines into factory contexts. Such projects provide a rich context for studying adaptive learning. Unexpected problems are common, and adaptation is important—both for developing new technical solutions, and for clarifying cause and effect relationships (Rosenberg 1982, Leonard-Barton 1988). Further, interaction among multiple actors (principally manufacturing engineers who work in the lab, and users who work in the plant) is important for diagnosing and resolving these problems (Tyre and Hauptman 1992).

The new process machines selected for study were currently in use in two unrelated factories of a large electronics manufacturer. The machines had been developed independently in two separate in-house labs, and were used in automated assembly of complex circuit boards. The first (called a solder paste profiler) automatically inspects the solder dabs that are applied to the board prior to component placement; the second machine (called a component placer) automatically places electronic components in the desired positions on the board. After the appropriate adaptations were made, each machine was described as successful by users and engineers and has since been replicated for use in other factories.

Sample of Adaptations Studied

Our sample contains 27 adaptations undertaken in response to users' problems with the new technology (15 affecting the placer, and 12 affecting the profiler). This represents all of those changes made to the new technology or in related procedures that met the following criteria. First, all changes were made after the equipment was installed in the production plant. Second, changes were undertaken in response to problems discovered by users. Third, data on the actions taken to investigate and resolve each problem were available from verbal report and plant records.

Problem symptoms included machine malfunction, unsatisfactory processing of parts, or user dissatisfaction with convenience or efficiency. Adaptations consisted of modifications to hardware or software elements of the machine or to users' procedures, as well as adjustments in engineers' and users' beliefs about cause-and-effect relationships.

Data Collection

Because we were interested in studying relatively large-scale aspects of problem solving behavior over long periods of time, we used a retrospective approach for gathering data. Our primary objective was to gather information on the problems that occurred with the two machines, and on the major actions taken to resolve those problems. We expected that retrospective accounts would enable us to focus our data gathering at an appropriate level of granularity, without getting deluged or distracted by the very detailed information that would emerge from a longitudinal, ethnographic study of technological problem solving. Our strategy was to use interviews and plant records to develop a synopsis of each problem, highlighting those events or decisions that were most salient to key participants in the problem solving process.

Data on machine problems and adaptive activities were collected through interviews with both the user of each machine (the process technician primarily in charge of the machine at the factory) and the engineer (the advanced manufacturing engineer primarily responsible for designing and debugging the machine). In both of the cases studied, the engineers maintained primary responsibility for diagnosing and resolving problems that occurred in the field throughout the test period.

Respondents were asked how they identified and resolved each problem in the sample. A primary interview question was, "Please describe changes that you made to the machine (or its surroundings, or techniques for using it) after its introduction." We then asked respondents to describe the problems that triggered each of these changes, and the actions taken to resolve problems. The initial questions were followed by more detailed probing (e.g., "Why did you travel to Plant A at that point?") so that we could develop a critical-event history of each problem.

Initial interviews were conducted on-site (at either the lab or the plant) where respondents could demonstrate the problems they described or could refer to logbooks. The interviews lasted from three to six hours, including plant tours. Respondents were interviewed both separately and, subsequently, together. Follow-up questions were discussed in additional face-to-face meetings, by telephone, and in electronic mail.

A strength of this approach was that our reconstruction of events and interactions was based on independent descriptions by different respondents (the engineer and the user). Where we found disagreement, we discussed it with respondents (often in joint meetings with both users and engineers) to discover the reason. Also, wherever possible we used specific memorable events or milestones that were available from plant records (such as the date when a new machine part was ordered) to serve as a memory aid or anchor.

Field notes were taken by both authors, and disagreements were discussed until consensus was reached. When ambiguity persisted, additional data were gathered. Coding of responses was also done by both authors and compared for consistency. Based on our field notes, we prepared a summary sheet on how each problem was resolved, including who first identified the problem, what major ideas were formulated and tested, what solutions were attempted, and where major chunks of problem solving activity occurred. To clarify the last issue, a "map" of problem solving activities (as shown in Figure 2) was prepared for each problem.

Results

Although we did not begin this study as an investigation of problem solving locations, a striking feature of problem solvers' descriptions of the adaptation process was their use of different physical settings for responding to a single problem. In 78% of the problems studied, the engineers had to go to the plant at some point in the problem solving process (see Figure 1). And almost all of these cases required that the engineers subsequently move back to the lab for more problem solving.[2] Thus, in 71% of all cases, engineers were obliged to investigate the same issue in two different locations (the plant and the lab). Moreover, in 40% of all cases, engineers moved between plant and lab three or more times. This is particularly significant since the decision to relocate problem solving was not a trivial one; each physical shift between the plant and the lab entailed two to three hours in driving time alone.

A major question that emerged from our observation of these moves was, what learning-related reasons did engineers have for relocating problem solving as frequently as they did? We first examined whether the problem solvers shifted between settings in order to facilitate collaboration with colleagues (users at the plant or technical colleagues at the lab).

Based on participants' descriptions of their activities, we inspected each problem-related visit to either the plant or the lab and recorded the set of problem solving activities that occurred in each place. A set of activities was classified as collaborative inquiry when there was evidence of significant conversation between engineers and users (or between engineers and their technical colleagues) relating to the problem or its solution. This definition encompasses the notion that "the essence [of collaborative inquiry] is that ideas grow out of conversations among participants" (Galegher et al. 1990, p. 2). Respondents described such interactions in terms of discussion, negotiation, argument, and the exchange of ideas. When there was evidence of interaction between engineers and users (or others) involving only simple requests (e.g., "Please do *x*"), or statements of fact (e.g., "Misplacements are occurring with *y* frequency"), or directions (e.g., "The best way to do that is like this"), we did not code the activities as collaborative inquiry. We coded moves between lab and plant as involving access to the physical setting when respondents (both engineers and users) described activities at a particular site as involving direct physical manipulation (e.g., undertaking experiments or test procedures) or observations of equipment, procedures, and setting. In these cases, activities were described in terms such as "She tested . . . ", "He tried" . . . , "I noticed . . . ", or "I saw . . . ."[3]

Our results reveal that engineers moved from the lab to the plant (or vice versa) because further progress required access to the other site for observation, experimentation, or direct manipulation of technologies and procedures, rather than for discussion or other forms of collaboration. Specifically, participants reported relocating problem solving activities between plant and lab a total of 61 times (or 2.33 times per problem); however, in only 13% of those instances did problem solvers' accounts of their activities during the visit highlight collaborative inquiry with others (see Table 1). More frequently (87% of all visits), problem solvers described their activities in such terms as watching, noticing, trying, and doing.

Of course, this does not mean that collaboration was totally absent from these situations. Very often, users or technical colleagues provided important support activities, such as operating production machines or lab equipment. Further, it is possible that brief interactions (e.g., a quick question or suggestion from users or technical colleagues) played a role in problem solving, yet did not surface in either developers' or users' retrospective accounts. But, it does appear that many of the shifts between lab and plant were motivated, in large part, by the need to locate problem solving activities in a specific setting.

Figure 1 **Number of Shifts Between Plant and Lab During Problem Solving (n = 27)**

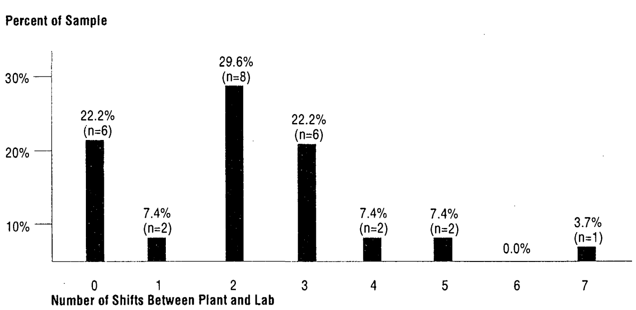
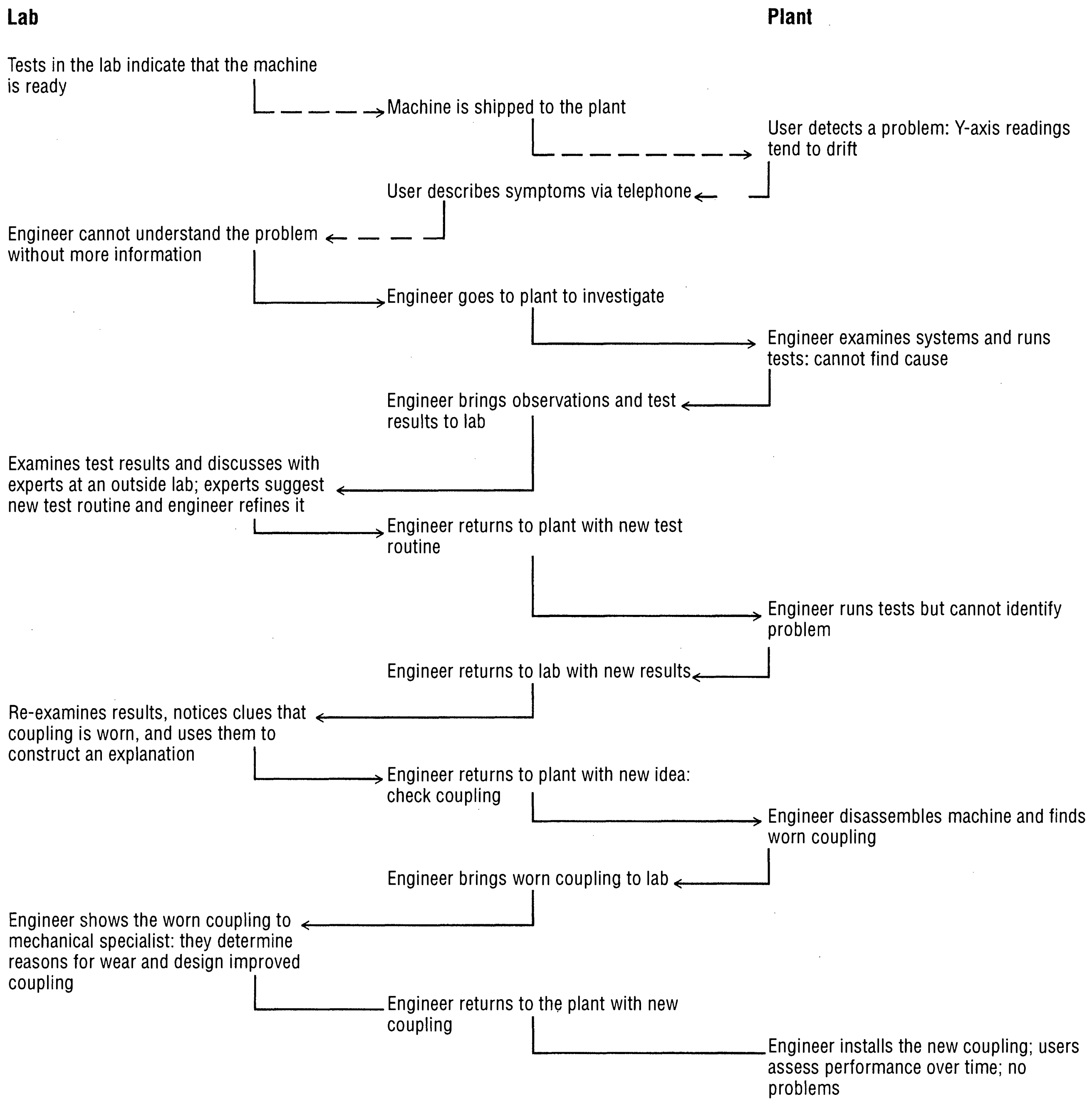


Figure 2 Physical Shifts in Solving a Complex Problem



The Importance of the Physical Setting

We identified several reasons why the physical setting of adaptive activities was often critical. First, because technical experts and users tended to see different things in any given setting, engineers frequently had to travel to the plant (or back to the lab) to discover clues embedded in that context that others did not "see." Second, the skills that expert problem solvers could apply to the problem partly depended on where they stood and the resources available there. Third, the physical setting affected not only what problem solvers could see and do, but also the unwritten rules and assumptions that guided their behavior, including their interactions with others. Finally, the physical setting

Table 1 Descriptions of Activities Highlight the Physical Situation of Problem Solving

	Frequency	Percent of All Problem-related Visits
Activities Performed at the Plant:		
(A) Problem solvers' accounts emphasize collaborative inquiry with user.	2	3%
(B) Problem solvers' accounts emphasize the use of other aspects of the local setting	33	54%
Total	35	57%
Activities Performed at the Lab:		
(A) Problem solvers' accounts emphasize collaborative inquiry with lab personnel	6	10%
(B) Problem solvers' accounts emphasize the use of other aspects of the local setting	20	33%
Total	26	43%

was important because problem solvers learned not only <u>in</u> physical settings, but also through alternation between different physical settings. Below, we discuss these four reasons in more detail.

Knowledgeable Action Involves Recognizing and Enacting Embedded Clues

Many critical clues to a machine problem or its solution were embedded in the plant or the lab—that is, they were difficult or impossible to discover unless the observer brought special skills to notice them. Engineers' technical knowledge and experience enabled them to recognize when local occurrences, operating patterns, or physical artifacts represented potentially informative clues to the underlying cause of the observed symptom. Thus, in only 2 of the 27 problems studied could engineers grasp the nature of the problem without some direct visual inspection of the problem in its context (see Appendix).

Engineers and technology users both recognized the importance of locally embedded clues. They repeatedly used the phrase, "you just had to be there." In describing one problem in the placement cell, the user explained, "We tried the telephone, the tube [electronic mail]...it was endless. You just had to be there and see it." The engineer agreed that "I just don't know what is going on until I see the problem. To look and know what I see is exactly what I get paid for!"

For example, in one case users had complained repeatedly that the placer machine was "drifting"; placements were gradually wandering out of tolerance over time. The engineer tried to investigate the problem over the phone. Based on descriptions from the user, he surmised that users must be programming the machine incorrectly. Since users always assured him that they were following instructions, progress was stymied. Finally the engineer went to the plant, and immediately noticed that two screws on the camera head had loosened. According to the engineer, "I saw it immediately and connected it with the drifting problem." And, once the engineer noticed the loose screws, this discovery "laid down a trace" (Schank 1982) to help guide further exploration.

Why did the users not notice this problem themselves? Different people attend to different stimuli, depending on what is surprising or anomalous for them (Neisser 1976). For the users, important anomalies were any deviations from the smooth processing of high-quality parts. Thus, they noticed detailed characteristics of the misplacements (number, timing, seriousness), but did not notice characteristics of the machine itself. Since the machine was new to them, their expectations about how machine elements ought to appear were still vague and provided them few opportunities to be surprised. By contrast, the engineers approached the plant with very specific expectations about how the machines ought to look during operations. In the example above, the engineer specifically (although implicitly) expected that the camera head screws would be tight, and thus he had the capacity to be surprised by their looseness.

Clues to machine problems were also discovered back in the lab. In one instance, the engineer went first to the plant to examine a problem involving light reflection off the circuit board surface. He was not sure how to proceed next, and returned to the lab to consider the issue. When he got there he encountered a colleague from another company carrying a circuit board with a very different surface coating design. The engineer examined the new board and, as he explained, he gradually "began to see" how the alternative design could help to alleviate the reflection problem.

In this example, the stimuli that led the engineer to develop a new solution simply did not exist in the plant. On the other hand, any other engineer would not have noticed the new board as a noteworthy clue to a potential solution, because other engineers did not have the reflection problem in mind at the time. Thus, engineers' ability to discover critical clues was a situated skill, and moreover was situated in more than one context.

Data Gathering as a Situated Skill

Another aspect of engineers' expertise was their skill in gathering relevant data. Even when engineers knew what information they needed, the information could not always be collected by a local user and conveyed by mail or phone call or even by face-to-face discussion. As one of the engineers explained,

> The form of data [that the user] uses is different, and the scheme he uses to collect it is not always clear to me, so you cannot just [use] his data .... The data I am interested in, the plant guys may have very little incentive to collect or use. And gathering data is not at all straightforward, because the picture that the user sees on the screen is not the same as what the machine sees.

Even if a given piece of information could be conveyed verbally from a remote setting, the interpretation of the message sometimes depended on where the hearer was located. For example, engineers told us on several occasions that they did not at first believe users' descriptions of machine problems because the behaviors that users described sounded "impossible." However, when engineers went to the plant, they discovered local idiosyncrasies (such as unexpected maintenance practices or operating procedures) that explained how an anomalous behavior could actually occur.

Knowledgeable Action Involves the Use of Local Tools and Resources

Engineers' skills also consisted, in part, in knowing how to use tools for gathering data (such as diagnostic software), for analyzing it (such as powerful computing resources), or for designing and implementing solutions. Since many of these tools were available only in a particular setting, this meant that engineers' abilities were partly dependent on the physical setting of the work. For example, engineers often had to go to the plant because they needed to use the diagnostic software routines embedded in the machine; at other times, they needed to go back to the lab to use specialized analytical instruments (e.g., oscilloscopes, microscopes) located there.

It is important to note that engineers' ability to use specific tools constituted an important aspect of their expertise. As Hutchins (1990) points out, tools and other physical artifacts do not just amplify people's cognitive skills, because considerable expertise is often needed to use them in the first place. Thus, "the act of getting into coordination with the artifact constitutes an expert performance by the person" (Hutchins, 1990, pp. 205–206). This was reflected in engineers' comments, such as the statement that "There is so much information in the machine [that] it takes a very specialized skill to absorb it."

Problem Solving Behaviors and Interactions Are Shaped by the Physical Setting

The place where problem solving occurred also affected the rules and assumptions guiding problem solvers' actions and decisions. As one engineer related, "when I am in the plant, I know that users are looking over my shoulder. I know that it is 'do or die' to find a solution—and fast." By contrast, when engineers worked at their labs, they found it easier to turn their attention away from quick fixes and toward the underlying reasons for machine problems.

Similarly, social interactions that contributed to problem solving were also embedded in their physical contexts. Aspects of the local setting could affect which interactions took place, how interactions were interpreted, and what they accomplished. For example, some users reported that they found it difficult to criticize new machines when they met with engineers at their labs, because they felt uncertain of themselves in the unfamiliar technical environment. Therefore, users and engineers found such meetings more productive when they occurred in the plant.

At the same time, social interactions partly shaped the physical setting by illuminating events or objects that otherwise would have gone unnoticed, as when the engineer "happened to notice" the circuit board with a new surface coating design. This discovery, in turn, led him to seek out the colleague who had designed the board and to engage him in discussion. Moreover, discussion with his colleague brought out aspects of the circuit board that the engineer had not perceived on his own. In other cases, when engineers went to the plant to investigate a problem, their noticing of physical clues provoked interaction with users, such as further questions about the symptoms observed. Input from users often led to discovery of additional physical clues. And, as engineers discovered additional clues or gathered more data, they were often better able to interpret users' comments and observations.

Interactions and discussions were also situated in the sense that local tools could be an integral part of collaborative inquiry. In one case, the engineer working on the profiler (who was an electrical engineer by training) brought a damaged machine component to the lab because she wanted to discuss possible causes for the failure with a mechanically oriented colleague. Since much of the colleague's expertise lay in his talent for using the diagnostic equipment in his lab, this equipment and the opportunities for action it presented were central to their joint inquiry.

A Dynamic View of the Learning Process: Alternation Between Plant and Lab Settings

We have presented some reasons why engineers' ability to learn from errors was situated in both the lab and the plant. Here, we add that what problem solvers could discover depended not just on where they stood, but also on where they had been and what they had seen there. Problem solvers "saw" things differently, or saw different things, depending on what they had already been exposed to in other settings. Thus, situated learning had a dynamic quality, often requiring learners to alternate between two physical settings.

In many cases, an engineer could not do everything she needed to do in a single visit to the plant. She might not know enough to recognize embedded clues, or to take advantage of the tools or information located in that setting. However, if her understanding of a particular problem evolved during a subsequent visit to the lab, she could then go back to the plant and recognize previously unnoticed clues or make good use of previously unused resources located there. This meant that there was a *dynamic* interaction between the "knowledge in" particular settings (in the form of clues, or needed tools and resources, or relevant information) and the understanding in the engineer's head.

This dynamic interaction shows up as a zigzag pattern in the location of problem solving, as engineers alternated between problem solving in the plant and problem solving in the lab. A good example is the case in which users of the profiler complained that the machine's *Y*-axis was "drifting." The engineer involved in that project had to relocate her investigation from plant to lab and back again seven different times before she traced the problem to a worn coupling inside the machine. (The process is described graphically in Figure 2.) As a physical matter, of course, the coupling was available in the plant throughout the period, and the engineer had always known how to disassemble the machine and how to recognize signs of wear. However, the engineer needed to undertake considerable investigation in both the plant and the lab before she learned enough to think of coupling wear as the source of the problem. Only at that point did the coupling become a salient part of the plant environment in the engineer's eyes.

This case was an extreme one, yet it was frequently true that, as engineers made discoveries or collected data in one site, they became better able to exploit the knowledge in another setting. This explains why, in most of the cases studied, skillful adaptive activity entailed alternating between different physical settings.

Discussion

This paper has examined one example of adaptive learning processes in organizations: responding to technical problems with new process machinery. Our findings serve as a reminder that theories describing learning and problem solving in physically decontextualized, abstract ways tell only part of the story, because the ability to understand and resolve problems is only partly carried in experts' heads. It also resides in experts' use of their physical settings to recognize embedded clues, to exploit specialized tools, and to find and interpret relevant information.

This has important implications for the way we think about learning and problem solving in organizations. For example, consider Simon's (1981, p. 153) suggestion that "solving a problem simply means representing it so as to make the solution transparent." Typically, the representational choices are described in terms of mental frameworks, conceptual diagrams, or computational models. Organizational theorists have added that <u>who</u> is involved in the investigation—in terms of functional or demographic characteristics—also helps to frame the problem (e.g., Katz 1982). We have shown that another influence on how problems are seen and how they are enacted is problem solvers' physical context, because different locations embody the potential for different kinds of informed discovery and knowledgeable action.

Our results raise the question, in what sort of problem solving situations is the physical context, and alternation between contexts, an especially critical aspect of the learning process? A preliminary hypothesis is that the physical context(s) will be most important for dealing with unfamiliar, unstructured problems. These problems often demand that unexpected clues be discovered and then used to invent new insights and new solutions (March and Olsen 1975, Weick 1990). Since the setting determines which clues can be discovered, it can have an important impact on how unstructured problems come to be understood. Further, alternation between settings can be important for dealing with unstructured problems because it provides opportunities to repeatedly reframe a problem as knowledge and experience grow. By contrast, where problems are more familiar and well-structured, physical location may be less important because problem solvers understand more clearly what data must be collected, how it should be collected, and how to interpret it, no matter where they are located.

The nature of the technical environment and the actors involved could also partly determine the importance of problem solvers' physical location. For example, where users' skills are largely tacit, we would expect that problem solvers would need to observe actual patterns of use in the operating setting before they could understand and diagnose problems. The same thing would occur whenever verbal communication is difficult, such as when individuals come from different backgrounds or speak different languages. Finally, we would expect that the more differentiated the work settings (e.g., plant vs. lab, or field site vs. headquarters, etc.), the more valuable it will be for problem solvers to move between different locations in order to exploit the wide variety of resources, people, and ideas available.

Our results also suggest that even when moving between different locations is not absolutely required for resolving a problem, it may still be beneficial to do so. Since the places where people live and work are "culturally ordered spaces" (Lave 1988) with their own unwritten rules about what is important and how things work, moving to a new location can encourage a new way of thinking about a familiar problem. It may also reveal unexpected insights. For example, one of the engineers we interviewed knew how to recognize and solve a common user problem via telephone. On the other hand, when the engineer went to the plant and observed an occurrence of this problem, he realized that users' operating routines were contributing to the technical problem in unexpected ways. He was then able to suggest changes in local routines to permanently reduce the incidence of this problem.

Another way in which movement across locations can enhance problem solving is by inserting a pause in the action while actors travel to a new site. This provides a chance to rethink and reframe problems beyond the pressures or routines of either work setting (Simon 1966). Finally, when problem solvers move between different organizational locations, they help to diffuse the knowledge embedded in one physical context to other parts of the organization.

These ideas have several managerial implications. In the popular literature, the need for co-location of project teams is widely emphasized. Ironically, however, the importance of the location itself is seldom taken into account. Our work suggests that managers should consider what kinds of knowledge and what forms of search are most important to a team's progress at any given time, and should select a location for the work accordingly. Notably, different physical settings may be appropriate for different phases of the work. Further, since complex organizations are by necessity geographically distributed, shifting team members among different locations is valuable because it enables the team to exploit the clues, ideas, resources, and people located in multiple sites.

Our findings also call into question some of the ways in which "experts" and expertise are commonly managed in organizations. Managers and theorists tend to assume that expertise is something that people carry around in their heads. Thus, experts are often placed in central locations and are expected to impart their knowledge to others through strictly verbal means. For example, in computer software and hardware firms, experts answer help lines but have no opportunities to move to the user's site (Pentland 1992). Similarly, doctors see patients, but not the physical settings where patients experience problems. In other cases, technical experts are assigned to specific operating contexts, and seldom or never move back to central labs. A more contextualized view of expertise would instead acknowledge that part of specialists' capabilities stems from the ability to unravel problems by working in *multiple* contexts (for example, in the centralized lab *and* in the local user site). Managers working from this model might shift their focus from trying to optimize the placement of experts (whether centralized or decentralized), and instead devote more attention to the question of how to facilitate the movement of experts as they seek to untangle problems and their causes.

The perspective taken in this paper also has implications for the management of those who use technology. A decontextualized understanding of expertise makes it difficult for managers to utilize the often tacit, highly situated knowledge of users such as machine operators, secretaries, or customers. Too often, input from these people is collected in strictly verbal form, with the result that users' input appears superficial or even inaccurate. By contrast, observing users *in* their normal work environments can enable managers or experts to develop a rich, contextualized appreciation of the issues that users describe.

Finally, our results force us to question some currently popular assumptions about the power of electronic media to link "knowledge workers" within or across organizations. Existing electronic media can provide excellent vehicles for sharing ideas, documents, or designs; however, they are limited because they are decontextualized. A rich set of potential clues and subtle influences embedded in a given location remains inaccessible to those who visit by computer.

In sum, this research suggests that both theory and practice could be enriched by paying attention to the role of different physical settings in the learning process. Such a view might lead to intriguing changes, both in the way that technology-based organizations are designed and managed, and in our understanding of how knowledge is applied and expanded in such organizations. We look forward to further research that will give us a deeper understanding of the role of physical context in adaptive organizational learning.

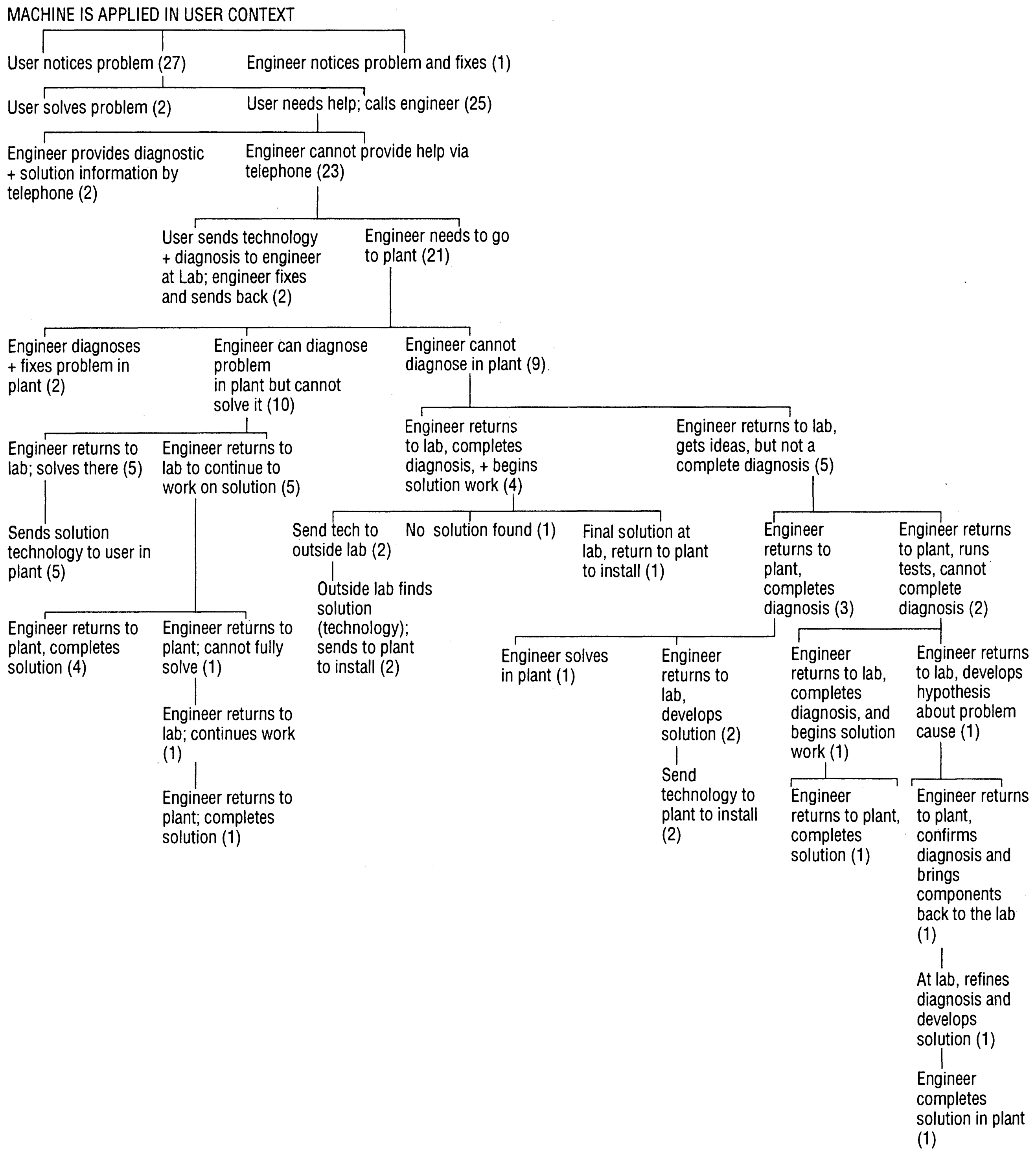
Endnotes

[1] It is worth noting that several scholars in related fields have recently focused on the importance of seeing—in several senses—for improving design processes. Schon and Wiggins (1992) describe the multiple "kinds of seeing" involved in the interaction between a designer (e.g., an architect) and her physical design (e.g., a drawing). Leonard-Barton (1991) shows that examination of a physical object (e.g., a prototype of a new product) can sometimes be a powerful vehicle for meaningful communication among designers and users.

[2] Shifts between plant and lab that were undertaken for reasons unrelated to problem solving (e.g., to attend a regular staff meeting at the lab) are excluded from this count.

[3] One concern with our data might be that collaborative inquiry was present, but omitted from verbal reports because developers wished to portray themselves as solely responsible for all adaptations. This does not appear to be the case, since users' descriptions of the adaptive process corroborated developers' versions.

Appendix **Physical Shifts in the Process of Diagnosing and Solving Problems**
Numbers in parentheses are number of cases in each category



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Accepted by Andrew Van de Ven; received May 1993. This paper has been with the authors for three revisions.