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LEARNING FROM ORGANIZATIONAL EXPERIENCE

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ABSTRACT

Learning-in-action, the cyclical interplay of thinking and doing, is increasingly important for organizations as environments and required capabilities become more complex and interdependent. Organizational learning involves both a desire to learn and supportive structures and mechanisms. We draw upon three case studies from the nuclear power and chemical industries to illustrate a four-stage model of organizational learning: (1) local stage of decentralized learning by individuals and work groups, (2) control stage of fixing problems and complying with rules, (3) open stage of acknowledgement of doubt and motivation to learn, and (4) deep learning stage of skillful inquiry and systemic mental models. These four stages differ on whether learning is primarily single-loop or double-loop, i.e., whether the organization can surface and challenge the assumptions and mental models underlying behavior, and whether learning is relatively improvised or structured. The case studies illustrate how organizations learn differently from experience, the details of learning practices, and the nature of stage transitions among learning practices.

Learning From Organizational Experience[1]

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ORGANIZATIONAL LEARNING

Learning-in-action, the cyclical interplay of thinking and doing (Argyris & Schön, 1996; Daft & Weick, 1984; Kolb, 1984), is increasingly important for organizations as they struggle to cope with rapidly changing environments and more complex and interdependent sets of knowledge. We define *learning* as a change in the likelihood that behaviors will be imagined or enacted in specific situations, and *organizational* learning as an analogous change at an organizational level.[2] Whereas learning is a *process* of change, the *content* of that process, the situation-action linkages, is *knowledge* (broadly construed to include explicit information, tacit know-how, etc.). Organizational knowledge is embodied in physical artifacts (equipment, layout, databases, documents), organizational structures (roles, reward systems, procedures), and people (skills, values,

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[2] This is similar to Argyris & Schön's (1996) definition of theories of action as propositions of the form "if you intend to produce consequence C in situation S, then do [action] A" (p. 13). We preserve the form of these propositions but relax the focus on intentional learning to acknowledge that learning can occur without intention or awareness, and even without observable action (Glynn, Lant, & Milliken, 1994).

beliefs, practices) (cf., Argote & Ingram, 2000; Levitt & March, 1988; Schein, 1992). Enactment or putting this knowledge to use requires combining component-level knowledge and filling gaps by improvisation (Weick, 1998). Enacting more unfamiliar, tacit, contextual, or contested knowledge requires more iterative, unpredictable, and emergent learning processes (Carlile, in press; Nonaka & Takeuchi, 1995).

Consider, for example, a factory producing some amount of product per unit time. During a visit to another factory, organization members observe that similar machines can be run at higher speeds. Yet, after returning to their factory, production remains at the same rate. Although individual human beings are naturally programmed to learn, organizations are not. Learning may be inhibited by adherence to traditions or bosses who insist, "this is the way we do things around here" (Oliver, 1992; Schein, 1992). Until external pressure, a vision, or an intrinsic motive engages new behaviors, there may be no measurable change in performance. If the factory does speed up production in response to competition, morale may erode, quality may drop, machines may break down, and the factory may ultimately lose its customers. Learning does not have to be an improvement (Crossan, et al., 1995; Repenning & Sterman, 2000; cf. superstitious learning, Levitt & March, 1988). If management decides instead to reorganize the plant into a lean production system rather than simply speeding up the machines and the people, then the factory would need time to try out unfamiliar actions and coordinate the various components to climb a learning curve (Argote, 1999) and avoid a learning failure (e.g., Repenning & Sterman, 2000).

A fundamental issue in organizational learning is how knowledge emerges and flows across boundaries: interpersonal, cross-team, cross-function, inter-unit, and interorganization (Crosson, Lane, & White, 1999; Kim, 1993; Nonaka & Takeuchi, 1995). Bridging across these "thought worlds" (Dougherty, 1992) requires common experiences and common referents, which are developed in bridging practices (Carlile, in press; Cook & Brown, 1999) including cooperative action, shared representations, collaborative reflection, and exchanges of personnel (Gruenfeld, Martorana, & Fan, 2000). Carroll (1998) and Popper & Lipshitz (1998) list organizational learning structures and practices such as benchmarking, job rotations, after action review, and databases for knowledge management. Learning is supported by organizational slack (Schulman, 1993) and human capital investments in conflict management skills to enable diverse group members to work with one another (Jehn, Northcraft, & Neale, 1999), inquiry skills to enhance conversations and surface assumptions (Isaacs, 1999), and systems thinking skills to link a wider variety of information into actionable models (Senge, 1990).

In the course of a decade of research on organizational learning in nuclear power plants and chemical plants, we have noticed a pattern in how various plants approach the challenges of developing learning capabilities. We noted apparent long-term effects of industry-level phenomena such as disasters (Three Mile Island, Chernobyl, Bhopal) and anticipated deregulation, regulatory pressure for self-improvement (Carroll & Hatakenaka, 2001; Jackson, 1996), and corporate-level shifts in policies and resources following economic hardship (Marcus & Nichols, 1998). Many plants were adept at incremental learning or adaptations that exploit familiar routines without challenging underlying assumptions ("single-loop learning" Argyris & Schon, 1996). Some plants struggled to move beyond "band-aids" and quick fixes toward more effective actions based on deeper understanding of systemic causes (Carroll, 1998). But challenging assumptions and changing mental models ("double-loop learning" Argyris & Schon, 1996) required unfamiliar analytical and social skills and unusual political support.

In this paper, we present a stage model of organizational learning and illustrate transitions among the stages with three case studies from the nuclear power and chemical industries. Although "high-hazard" industries (Perrow, 1984) such as nuclear power and chemicals have special challenges in learning because trial and error is so costly (Weick, 1987), their efforts to develop learning capabilities are instructive for all organizations.

A STAGE MODEL OF ORGANIZATIONAL LEARNING

Stage models are common in organization theory, for example in descriptions of organizational life-cycles (e.g., Quinn & Cameron, 1983) and in historical analyses of organizational forms over time (Chandler, 1962; Malone & Smith, 1988; Perrow, 1970). The four stages in Figure 1 are presented as a provocative guide to analysis, not as a rigid model of development. In any organization, there will be examples of each stage in operation in different parts of the organization and at different moments in time. It is healthy for organizations to use multiple learning mechanisms at many organizational levels (individual, team, department, and so forth) in order to draw on a wide range of capabilities and enable a creative tension between different approaches (Crosson & Hurst, 2001; Crosson et al., 1999; Weick et al., 1999). However, the latter stages require shared understanding and collaborative effort across the organization, so these capabilities must become relatively widespread and commonly enacted if they are to be sustained. Although we propose that these stages and capabilities tend to emerge in a particular order, being “at” a stage means that there is relatively more behavior consistent with that stage and *earlier* stages.

Insert Figure 1

Local Stage

In what we label the Local Stage, there is considerable organization-specific and task-specific knowledge that is contextual (Carlile, in press), tacit (Nonaka & Takeuchi, 1995), and sticky or hard to transfer (von Hippel, 1994). Exceptions occur frequently, and decisions are made locally by those steeped in the details. The organization relies on technical expertise to cope with surprises and provide flexibility or resilience (Wildavsky, 1988). Learning mostly occurs locally and information does not travel easily beyond particular workgroups and contexts.

For example, like most organizations that start and often remain small (Aldrich, 1999), early nuclear power plants began as small demonstrations of possible designs, which were later scaled up for economic efficiency. Although they were more proceduralized than fossil fuel plants, nuclear power plants were similar in drawing knowledge from the experiences and skills of craft workers and sharing the attitude of “run it ‘til it breaks.” Design engineers appear to have understood plant construction as a finite project to build a production machine. Once built and debugged, the plants were expected simply to run, a belief echoed by nuclear utilities *and* regulators: "Technological enthusiasts heading the AEC [Atomic Energy Commission] believed most accidents were too unlikely to worry about" (Jasper, 1990, p. 52). Given this belief, little attention was paid to “minor” problems in a plant or other plants in the industry, unless those problems affected production.

When a combination of minor problems and operators doing what they were trained to do produced the Three Mile Island (TMI) event in 1979, this constituted a "fundamental surprise" (Lanir, 1986) for the nuclear power industry. The information needed to prevent the TMI event had been available from similar prior incidents at other plants, recurrent problems with the same equipment at TMI, and engineers’ critiques that operators had been taught to do the wrong thing in particular circumstances, yet nothing had been done to incorporate this local information into plant-wide or industry-wide operating practices (Marcus, Bromiley, & Nichols, 1989). In reflecting on TMI, the utility’s president Herman Dieckamp said,

> To me that is probably one of the most significant learnings of the whole accident [TMI] the degree to which the inadequacies of that experience feedback loop... significantly contributed to making us and the plant vulnerable to this accident. (Kemeny, et al., 1979, p. 192)

Control Stage

Growth in terms of size and complexity is a major driver of formalization (e.g., Pugh et al, 1969). To achieve economies of scale, expertise is organized into workgroups and departments that often become classic “silos” of knowledge. To coordinate efficiently among workgroups and other subunits, organizations generate standard operating procedures and other formal routines (Nelson & Winter, 1981; Levitt & March, 1988). Controls are instituted to encourage uniformity, including accounting controls, procedure manuals, training programs, planning processes, and so forth. Learning is understood as a set of routines such as training, performance feedback, and statistical process control (Sitkin et al, 1994). When organizations are forced by repeated failure or stakeholder pressure to initiate changes, they may seek to copy success stories (e.g., start a TQM program, Cole, 1998) rather than to rethink assumptions and reshape the organization. Learning is directed at maintaining control through exploitation of the known rather than exploration of the unknown (March, 1991), single-loop evolutionary enhancements rather than double-loop revolutionary changes (Argyris & Schön, 1996).

For most of its history, the nuclear power industry attempted to improve operations and prevent accidents through creation and enforcement of bureaucratic controls. The desire for control is compatible with the norms of the engineering profession that have shaped many industries such as nuclear power (Rochlin & von Meier, 1994). Elaborate probabilistic analyses were used to anticipate (Wildavsky, 1988) all possible failure paths and to design physical and procedural barriers to these paths. When problems occurred, investigations typically identified actions that failed to comply with the rules, such as operators who did not follow procedures or engineers who made erroneous calculations (Carroll, 1995; Reason, 1990). Problems stimulated blame that undermined information flow and learning (Morris & Moore, 2000; O'Reilly, 1978). Line managers expected concrete solutions that would strengthen control mechanisms (more training, more supervision, more discipline), create more rules (more detailed procedures, more regulatory requirements), or design hazards and humans out of the system (according to technical design rules, e.g., "inherently safe" nuclear reactor designs).

Open Stage

Large, conservative, bureaucratic organizations can be highly successful in stable environments, but in turbulent and unpredictable environments, they do not learn or change fast enough, often ignoring threats (e.g., Cole, 1998; Freeman, 1999). Working harder to achieve consistency and efficiency may preclude "working smarter" for fundamental process improvement because such initiatives divert resources away from current production (Repenning & Sterman, 2000). Eventually, increased pressure and enlightened employees at various levels may open the organization to self-analysis, recognition of uncertainty, elaboration of learning mechanisms, and innovation (Quinn & Cameron, 1993).

In the nuclear power industry, regulators and industry groups have long been calling for greater awareness of minor incidents and actions to avoid future trouble (Jackson, 1996; Rochlin, 1993). Today, a typical nuclear power plant may identify over 2000 problems or incidents per year, 90% of which would have been ignored in the past. As Weick & Sutcliffe (2001) state, "to move toward high reliability is to enlarge what people monitor, expect, and fear" (p. 91). Although efforts to accelerate learning may include technological initiatives such as web-based information exchanges and databases of new ideas and best-practice routines (Pan & Scarbrough, 1998; Davenport & Prusak, 1997), the open stage is based on attitudes and cultural values of genuine curiosity, involvement, sharing, and mutual respect, and a climate of psychological safety (Edmondson, 1999).

Deep Learning Stage

The final stage, as we envision it, builds upon the open stage by adding more capability for understanding deep, systemic causes and creating a wider range of action possibilities to address such causes. Organizations at this stage are capable not only of mutual respect across internal and external boundaries, but also of skillful inquiry and facility to gain insights, challenge assumptions, surface existing frames, and create comprehensive models (Argyris & Schön, 1996; Senge, 1990). Analyses are based on facts but connect logically to systemic, organizational, cultural, and political viewpoints and experience with a repertoire of actions that can change these deep structures.

Deep learning practices are not widespread in the nuclear power and chemical industries. Even the best plants struggle with analyzing below the level of equipment problems, human error, and procedure inadequacies (Carroll, 1995, 1998, Carroll et al, 2001). Despite a desire to improve, investigators and managers seldom look for fundamental or deep, systemic causes because they lack ready-made actions to address such issues and ways of evaluating their success (remnants of the control stage). Carroll, Sterman, & Marcus (1998) relate one example of an innovative technique that introduced such practices to Du Pont chemical plants, based on a system dynamics model turned into an interactive game. In our third case, we present another example that shows how this transition requires attention, resources, and discipline.

In the remainder of this chapter, we present three case studies of organizations that made significant transitions from stage to stage. Presenting the cases as transitions clarifies the differences between stages and illustrates the challenges of changing behavior, emotions, and mental models. It also allows us to emphasize that organizations are now, and may always be, in transition. Following the case studies, we draw some lessons about organizational learning and the stage model.

A SHIFT FROM LOCAL TO CONTROL STAGE

In the first case study, a nuclear power plant investigated an incident in which an employee was seriously hurt. This plant was attempting to improve safety and performance in part by using a newly upgraded problem investigation process. The investigation created an opportunity to raise collective awareness about local work practices and helped managers strengthen controls and increase conformity to rules.

Fall from Roof

An electrical maintenance supervisor sent three men to replace light bulbs inside the "hot" machine shop, the area used to decontaminate equipment of radiological residue. The men headed off to the work area and discussed among themselves how to reach the light bulbs. They decided that one of them, whom we call Joe, would access the lights by climbing on the roof of a shed within the larger building. Joe and one coworker dressed in anti-contamination suits and propped a ladder against the shed wall. Joe crawled up the ladder and onto the roof. As he was about to reach the lights, one of the roof panels gave way, dumping him 10 feet to the ground below. His injuries included a broken scapula, a broken rib, three fractures to the small bones near the spine, a lacerated lung and arm. His coworkers called EMTs who took Joe to the hospital.

The Plant's Interpretation

For an event of this seriousness, a multi-discipline team was assembled to collect information, analyze causes, and make recommendations. The team noted that a number of standard operating procedures regarding safety assessment were not followed. When the electrical supervisor assigned three men to the job, no one was designated to be in charge. The supervisor did not conduct a pre-job brief (explaining the operational and safety issues involved in the job) and no one thought to walk down the job (conduct physical examination and discussion of the safety challenges at the work site) or plan the safest way to do the job. The workers failed to follow rules requiring fall protection (e.g., when aloft, wear a harness attached to a fixed support) and proper use of a folding ladder (unfold it, don't lean it against a wall).

The team's report noted that these actions and omissions may be part of a local culture of inappropriate risk-taking. The tone of the task was set, in part, by the most senior electrical worker of the three and the only one who had changed these light bulbs before. He told the others that they would "love this job 'cause it's kind of tight up there." Based on their interviews with Joe and others, the investigators speculated that this challenge struck Joe, who had just transferred to this department, as an "opportunity to succeed." Lastly, the workers ignored warning signs that the job was not routine. Nobody raised questions when Joe was advised to stay on the one and a half-inch steel framework of the building because it was the strongest part. Joe failed to reconsider the job when his hand slipped through a skylight and he nearly fell, shortly before slipping again and falling through.

The investigation team's report documented lack of compliance with established safety practices and suggested ways to enhance compliance with existing rules. The report concluded that, "The cause of the accident was a failure of the employee, the employee in charge, and the supervisor to properly follow the Accident Prevention

Manual requirements for working in elevated positions." The report then recommended that the plant should: 1) raise sensitivity to safety on routine jobs by appointing a full-time safety person; require managers to communicate to supervisors and supervisors communicate to employees the plant's expectations regarding industrial safety; and require department managers to provide feedback to the plant manager on each department's safety issues; 2) make more detailed guidelines on working aloft available to employees; 3) consider instituting a company-wide program on "Working in Elevated Positions," and 4) counsel all employees involved in the incident.

Making the Transition Between Organizational Learning Stages

The investigation illustrates the plant's effort to shift its learning orientation from local to control. The report highlights the failure of workers and first line supervisor to comply with existing rules and procedures. The corrective actions' aim to increase awareness and compliance with rules. Information was generated about local work practices that could be shared across groups, discussed openly, and used to institutionalize new work procedures. The focus is on changing actions to comply with rules in order to correct a mismatch between desired results (keep people safe) and actual results (Joe is hurt), i.e., single-loop learning (Argyris & Schön, 1996).

In a control-oriented organization, managers are judged by their lack of problems or the speed with which problems are resolved and control reasserted. There is a contest for control between managers and engineers who are labeled as strategists and designers of the plant and operators and maintenance people who are labeled as implementers and doers (Carroll, 1998; Schein, 1996). Challenges to that control are threatening and become political issues (Carroll, 1995; Tetlock, 1983). As one member of the investigation team commented, “We put together three different drafts and each time someone in upper management disagreed with what we wrote. Finally the plant manager stepped in and accepted our answer.” Without the opportunity to challenge underlying assumptions about status, careers, rules, hierarchy, and expertise and the chance to reshape work accordingly, employees tend to feel that “improvements” are simply another layer of control imposed on them (cf. employee voice, Adler & Borys, 1996).

A SHIFT FROM CONTROL TO OPEN STAGE

The second case describes an organization-wide change effort in response to a crisis that shut down a large nuclear power station and nearly bankrupted the utility. It is a stark reminder of the importance of people in technically-dominated companies.

The Millstone Culture Implosion

In October 1996, the Millstone nuclear power station outside New London, Connecticut, received an unprecedented order from the US Nuclear Regulatory Commission (NRC) to keep its plants closed until they could demonstrate a “safety conscious work environment.” The problem had come to public attention earlier through a cover story in Time magazine about harassment and intimidation of employees who brought safety concerns to management. The NRC review (Hannon et al., 1996) concluded that there was an unhealthy work environment, which did not tolerate dissenting views and stifled questioning attitudes among employees, and therefore failed to learn and change. As the report said, “Every problem identified during this review had been previously identified to Northeast Utilities management… yet the same problems were allowed to continue.”

The Plant's Interpretation

In September 1996, the new CEO for Nuclear Power, Bruce Kenyon, set the scene for change by an address to all employees on his first day, in which he introduced his values: high standards, openness and honesty, commitment to do what was right and two-way communications. He immediately revamped the Millstone top management team and strengthened the Employee Concerns Program.

Kenyon's subsequent actions enacted and modeled openness and trust. Throughout the next months, he met regularly with small work groups and in large all-hands meetings to give information and encourage two-way communication: "It shocked them to get candid answers."[3] Upon hearing Kenyon say publicly at his first NRC meeting that he found the organizations "essentially dysfunctional," an interviewee from the NRC remembers thinking, "here's a fellow who at least recognizes the problem." Based on recommendations from an employee task force redesigning the Employee Concerns Program, Kenyon agreed to create an Employee Concerns Oversight Panel (ECOP) to have an independent voice and report directly to him. ECOP was staffed with passionate advocates who argued with each other and with management, but over time they evolved a workable role. The panel's existence "sent a message to the work force that employees could act as oversight of management."

Kenyon allowed himself to be fallible and to enlist participation. When two contractors were terminated on the grounds of poor performance and the Director of the Employee Concerns Program provided evidence that the terminations had been improper, Kenyon quickly reversed his decision. As one of his senior managers recalls about their

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uotations are from interviews by Carroll & Hatakenaka (2001) working relationship, Kenyon "went along with all my recommendations. He didn't always agree… [Sometimes he] swallowed hard."

Individual managers experienced personal transformations that changed how they understood the nature of the problems. Typical of the old-style management, the operations vice president was weary of "whiners," and "didn't believe anyone would harass someone who brought forth safety concerns." When the two contractors were terminated and the Employee Concerns Program offered their view that the terminations were improper, "It was one of those moments your perception changes... a watershed for me."

Multiple mechanisms and forums allowed broad participation so that managers and employees could share information, develop common language, learn by doing, and build trust by reacting well to challenges. We have already mentioned the Employee Concerns Program (ECP) that provided confidential ways to report issues for investigation and the Employee Concerns Oversight Panel (ECOP) that gave a direct connection between employee representatives and the CEO Nuclear. The Executive Review Board was created after the contractor terminations to review all disciplinary actions, comprising senior managers and an ECOP representative as an observer. By opening up the management process, it helped restore employee trust in management, and created an environment for managers to learn and enact new values. The People Team, a coordinating group among human resources, legal department, ECP, ECOP, management, and organizational development consultants, met daily to respond to problems and organize to address issues and monitor progress. Internal Oversight groups and an independent third-party consulting group required by the NRC provided additional monitoring and advice.

Making the Transition Between Organizational Learning Stages

The NRC requirement that Millstone develop a “safety conscious work environment” and demonstrate this to the satisfaction of an independent third-party consultant was unprecedented in the industry. The NRC offered no guidance. Millstone had to find its own way to move from a control stage characterized by centralized authority and mutual suspicion to an open stage characterized by communication, trust, and participation.

New senior management, external intervention, and an infusion of outside employees broke through managers’ defensiveness and pride in Millstone’s excellent prior record in the industry, built on technical excellence. Managers’ basic assumption that “we know everything we need to know” was challenged (cf. Schulman, 1993). And so was employees’ basic assumption that “management can’t be trusted.” Because senior management reacted well to critical events such as the contractor terminations and independent voices were allowed to challenge the status quo, double-loop learning occurred. Multiple venues emerged for managers and employees to talk together and work on the common problem of rebuilding Millstone. Managers began to listen and trust the employees enough to act on what was being said; in turn, employees began to feel safer about speaking out (Edmondson, 1999) and to trust that management would listen and take action. The most powerful way to regain trust is to work together with a common purpose (Kramer, 1999; Whitener, Brodt, Korsgaard, & Werner, 1998).

Managers not only became more open to information coming from employees and external observers, but also became aware of new kinds of information. Millstone was typical of an industry in which managers are "not high on people skills, for example, few can read nonverbal signals." Control-oriented managers, some of whom get their way by yelling and threatening, are generally unaware of their own emotionality and try to restrict any emotionality in their subordinates. They claim to value facts and rationality, even when they are using fear to exercise control. The more open environment at Millstone marked an increase in interpersonal skills and emotional intelligence (Goleman, 1995; Hirshhorn, 1993). Through extensive new training programs and coaching by organizational development consultants, managers were able to "learn the difference between anger, hurt, and a chilling effect" and avoid confusing a fear of reprisal with a lack of confidence that management would take effective action.

A SHIFT TO DEEP LEARNING

At a petrochemical plant, the new plant manager initiated a plant-wide effort to use problem investigation teams as a way to address, simultaneously, a recent history of financial losses, some dangerous incidents, and repeated equipment failures. A large-scale intervention[4] was organized by two corporate headquarters staff who had been promoting more strategic and systemic thinking at operational and executive levels in their company, using problem investigations (which they called "root cause analyses") as one of several approaches. Managers decided to expose about 20 plant employees, operators, maintenance staff, engineers, and first line supervisors to root cause analyses by dividing them into teams to explore four significant recent problems. Each problem investigation team included some members from inside and some from outside the plant

[4] They avoid calling this "training," which implies top-down control, and misses the larger desired impacts on managers and the culture in general.

and at least one experienced root cause facilitator (most from other plants). The overall process included presentations and practice sessions on investigation techniques, analytical tools, and reporting methods during the course of a three-week time frame, culminating in reports to plant management. The facilitation team timed each day's preparation to correspond to the needs of the teams as they collected maintenance and operations logs, reviewed physical evidence, interviewed involved parties and knowledgeable experts, analyzed causes, and prepared reports.

Charge Heater Fire

The charge heater fire investigation examined the explosion and fire in a charge heater that cost $16 Million for lost production and repairs. Charge heaters are large gas-fueled burners used in the transformation of waste products from oil refining back into usable products through hydrocracking, a dirty and dangerous process requiring very high heat and pressure. The residue of this process is coke (coal dust), which can accumulate on the inside of heater tubes. In addition to unearthing causes of the explosion, plant managers also wanted to discover and ameliorate the conditions that led to this event and might lead to future events.

While the causal analysis presented below may seem extremely straightforward, its simplicity is the result of a rigorous and laborious root cause analysis process that involved four elements: A time line of events that was sometimes detailed to the minute; an "Is/Is not" process that differentiates circumstances where the event occurred from similar circumstances where it did not (Kepner &Tregoe, 1981); a detailed causal event diagram; and a process of categorizing the quality of data used to draw inferences in the causal event diagram (as a verifiable fact, an inference, or a guess). In doing these analyses, members of the team argued with each other, built on each other's ideas, and alternated between amazement at and appreciation for the differences in each other's views of the refinery.

The Plant's Interpretation

Distilling and analyzing the information available, the team concluded that the fire was due to a tube rupture inside the charge heater that occurred when the three quarter inch steel skin of the tube got too hot and tore. The team found that three factors interacted to produce the fire. First, operators ran the burners in the charge heater unevenly to increase heat and thereby achieve the desired higher production level, while avoiding alarms that would signal an unsafe condition. Second, heat was removed more slowly than usual from the tube skin because coke had adhered to the inside of the tubes and was acting as an insulator. There was more coke than usual because it was assumed that a new decoking process worked as well as the previous process and no one had checked for coke build up. Third, the combination of running some tubes hotter (at a higher gas pressure) and the build-up of coke moved the maximum heat point up the tube. The thermocouple meant to detect temperature on the tube skin, set at a height specified in the heater design, was now below the hottest part of the tube, so that operators believed the tube temperature was acceptable. The tube ruptured above the thermocouple.

The team noted as a "Key Learning" that plant staff made decisions without questioning assumptions that seemed to underlie them. Team members were amazed at "how quick we jump to conclusions about things." First, the maintenance department changed decoking processes but did not know and never checked if the new process was effective. Second, operators increased the burner pressure in the charge heater to increase production but did not know the consequences of doing so. Third, operators changed the pattern of firing heater tubes (to fire hotter around the perimeter) but again did not know the consequences of doing so. They speculated that their colleagues probably were unaware of the assumptions they were making. On the basis of these insights, the team's first recommendation for future action was that the plant identify "side effects" and be more aware of the broader "decision context" when changing production processes.

Based on the insights from this team and from the other teams, the plant decided to implement a "Management of Change Process" to address the unanticipated side effects and interactions that caused problems. According to follow-up interviews with team members six months after their investigation, the actual results are mixed. One team member felt the plant Management of Change process had shown results:

> The biggest issue that came out [of the root cause analysis intervention] was management of change. MOC. Now people pay more attention to adhering to the MOC process. It may be that the RCA training helped focus attention on MOC. MOC is serious. It is real. If you don't do it, your job is on the line. If you do not do it, you have to explain why not.

However, another team member felt, "There are no legs on the management of change effort. It is just a lot of talk."

Making the Transition Between Organizational Learning Stages

The charge heater investigation provides examples of an organization increasing both openness and deep learning. The independent decisions that changed decoking and heater tube firing practices illustrate aspects of local learning. In our observations of the training session, it was evident that at least some participants were anxious about being open with colleagues in their own department or in other departments, or with management. Would operators talk to engineers? Would an operator working on this investigation be perceived as having sold out? Would managers listen to reports that were critical of their own behavior? The investigation could have blamed the operators for "getting around" the tube temperature alarms, ignored the role of management decisions about production goals, and instituted more monitoring and rules. A control approach to learning could have reinforced barriers to the open flow of information and discouraged participation, and failed to get at the underlying, systemic causes of the event.

However, plant management was not approaching its problems from the viewpoint of control. Instead, there was a desire to create more openness, and to demonstrate the value of openness and deep learning for achieving better performance. During the course of the training and investigation, teams experienced more openness and collaboration than they expected. There was a willingness to confront reality and to surface underlying assumptions about "how we do work around here." Support from a new plant manager helped encourage full participation. That support was itself an outcome of the training team who were working publicly with the investigation teams but privately meeting with management to reduce their defensiveness and enlist their visible engagement. And, it was evoked and reinforced by specific features of root cause analysis that require close attention to factual details, data quality, and cause-effect relationships.

The team investigation began to create deep learning when they started addressing operations at the plant from a systemic perspective and challenging assumptions. Paradoxically, the process of "drilling down" precisely and narrowly into causes of this incident allowed the team to develop new awareness of interdependencies across the system. In our interviews with team members, they universally highlighted the benefit of having a diverse team because of the surprising differences among people's ways of looking at the same problem. They recognized interactions among components of the system and began to understand a central tenet of the quality movement (e.g. Goldratt & Cox, 1992) that working to optimize individual components does not automatically add up to an optimized system. Most importantly, they developed and practiced double-loop learning capabilities to recognize assumptions and mental models as separate from reality (Friedman & Lipshitz, 1992) and take action with new mental models (Argyris, et al., 1985).

INSIGHTS ABOUT ORGANIZATIONAL LEARNING

A Framework for the Stages

The four organizational learning stages can be thought of as a progression, but the stages can also be examined for underlying dimensions and symmetries. In Figure 2, we organize the four stages into a 2 X 2 table[5] representing two dimensions: (1) single- and double-loop learning and (2) improvising and structuring. As we have discussed earlier in this paper, single-loop learning adjusts goal-oriented actions based on feedback to better achieve the same goal (Argyris, et al., 1985). In double-loop learning, a deeper

[5] Because there were four stages, we wondered whether they could be placed into a 2X2 table. The dimensions of the table were induced from the case studies and should be treated as provisional.

inquiry surfaces and challenges underlying assumptions and values regarding the selection of that goal. Improvising is a process of acting intuitively into an emerging situation rather than following structured procedures or plans (Weick, 1998). Structuring is about consistency and predictability embodied in routines and shared mental models.

Insert Figure 2

The above analysis offers several important insights. First, it emphasizes the importance of the two dimensions. The large, technologically-driven organizations that we have studied do not appear to transform all these elements at once or even to change them gradually. Instead, there is a natural order to their focus. Local learning is single-loop and improvised, emerging from work practices and life experiences. Control is exercised by adding structure but it remains single-loop because underlying assumptions are rarely considered or changed. Open learning is double-loop and improvised, as individuals awaken to the limitations of the organization and challenge assumptions about separate domains of technical expertise, compliance with rules, hierarchy, and so forth. Deep learning is double-loop and adds structure as new tools for inquiry and collaboration spread through the organization.

Second, progress through the stages zigzags through the dimensions. In particular, the transition from controlled to open involves changing *both* dimensions, moving from structured single-loop learning to improvised double-loop learning. Perhaps this is a reason why the transition is so difficult and organizations seem to get stuck in the control stage. Control through measurement, monitoring, incentives, and other traditional bureaucratic mechanisms seems to come naturally to managers and engineers (Carroll, 1998; Schein, 1996). Companies adopt programs such as TQM and learning organization more to copy success stories and achieve legitimacy rather than through commitment and understanding (Cole, 1998; Repenning & Sterman, 2000).

The most advanced of the companies we have studied are only beginning to recognize the limitations of top-down control and promote open exchange of information, motivated by a few subversive visionaries and the intense pressures of competition and regulation. The "questioning attitude" and "safety culture" advocated in these industries are directed at acknowledging doubt (Schulman, 1993), increasing awareness or mindfulness (Weick et al., 1999), creating psychological safety (Edmondson, 1999), respecting the contributions of others, and placing a positive value on teamwork and learning. Such trust can only be developed by observations of the experience of courageous pioneers who take early risks to tell the truth. When others validate open behavior, trust is built and openness spreads in a virtuous cycle.

Openness to learning becomes linked to a discipline for learning in the transition to what we call the deep learning stage. The complexity and pace of change of modern organizations requires more than a desire to learn. Special circumstances for learning and concepts and techniques that make learning more efficient are needed to break through long-held assumptions and cognitive habits. Deep learning is not simply the use of particular techniques such as root cause analysis. There are many versions of "root cause analysis," most of which are used with minimal training to find and fix problems (Carroll, 1995) rather than to challenge deep assumptions with rigorous and systemic thinking, just as TQM can be used for control rather than learning (Sitkin et al., 1994). It is not particular tools such as root cause analysis that lead to learning, but rethinking actions and assumptions in the context of new *concepts* that underlie the tools, such as data quality, rigorous cause-effect connections, systems thinking, mutual respect across groups, insight into personal and political relationships, and double-loop learning. The tools and the learning activities are only an opportunity to have new conversations, enact new behaviors, develop new skills, and build new relationships.

Learning-in-Action

The cases reinforce the importance of learning through action. Although some kinds of knowledge are represented explicitly (numbers, words) and easy to store and transfer, many kinds of knowledge have to be reconstructed by users, improvised, tried out and modified to suit the occasion. In the Fall From Roof case, team members learned through their investigation process and interaction with management, and the organization learned from its failure (the accident) and by enacting the corrective action process. The Millstone case offers the clearest example of policy and culture change requiring an interative process of trying out new behaviors, then adjusting behaviors and mental models to the reactions of participants and the emerging definitions of success. The Charge Heater Fire investigation appears on the surface to be the introduction of new investigation and analysis techniques, but upon deeper reflection it represents a negotiated interaction among managers and workers, and among multiple worker groups, to achieve a new relationship of openness and collaborative engagement.

Experience with learning cycles increased tolerance for short-term difficulties and occasioned resource shifts away from production toward learning. A systemic view suggests that things get worse before they get better (since resources are shifted away from immediate needs) and that leverage points must be identified for selective investment. Problems are not simply someone's fault, but rather a feature of the system; altering that system takes deep understanding and broad support. This is more than "controlling" people. System principles may be hard to verbalize yet possible to learn through action or instruction. For example, a rigid grip of a rowing oar may increase the feeling of control but decrease absorption of the shock of uneven waters, thereby decreasing actual control. Managers may use "heavyhanded" incentives and authority to increase their feeling of control and drive noncompliance out of sight, simultaneously increasing the discrepancy between rules and actual behavior.

In summary, we have argued for the importance and difficulty of learning from experience, particularly when meaning must emerge from local bits and pieces and the enactment of new practices in complex and rapidly changing environments. The history of these industries and the case studies we have examined suggest that there is a common progression from local learning to a control orientation associated with single-loop learning, which is then held in place by managerial and professional culture. Yet problems continue to occur and many organizations seek to be more proactive by becoming a learning organization, which incorporates mutually-reinforcing elements of attitudes and thinking patterns. Our results suggest that, to some degree at least, attitudes favorable to learning precede double-loop learning skills. The concepts and skills of deep learning seem to be difficult to master and to require significant commitment, discipline, and learning-in-action. Future research will undoubtedly put more flesh on the bones of this framework, and contribute alternative ways to think about organizational learning.

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Figure 1
The Four Stages of Organizational Learning

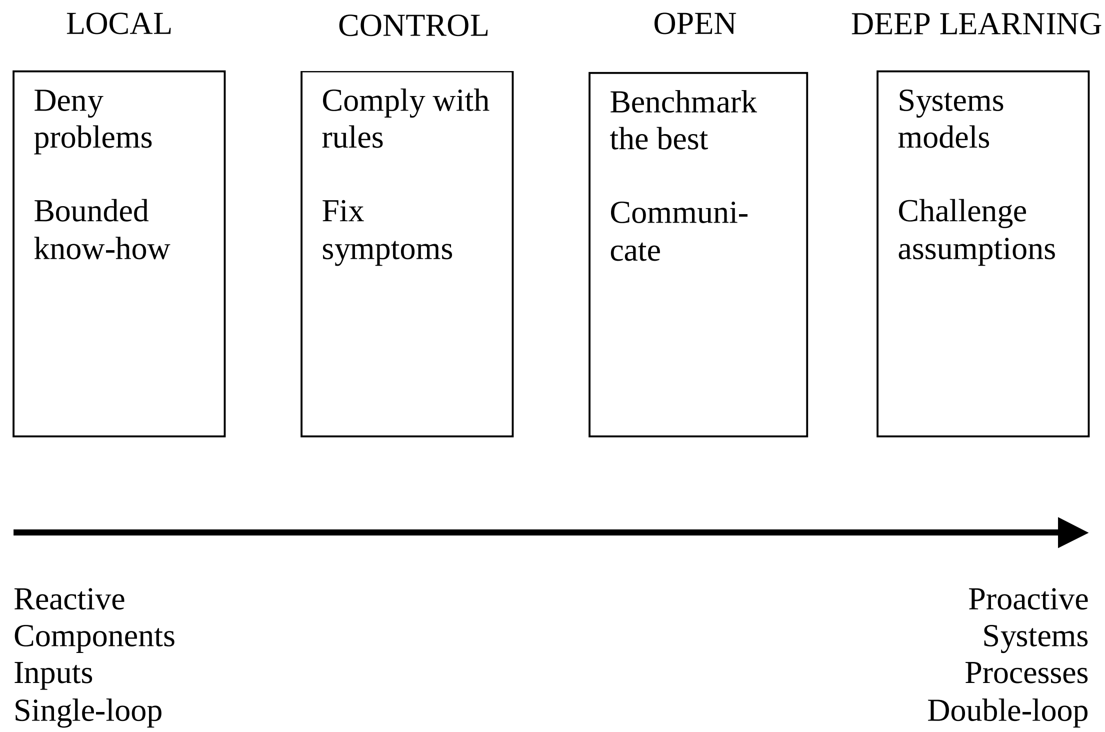

Figure 2
The Four Stages of Organizational Learning