THE CASE FOR EXPERIENTIAL KNOWLEDGE

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Abstract

It is argued that experiential knowledge is the essential ingredient in the kinds of organizational self-adaptation and self-design that make safe and reliable operation possible in highly complex, high-technology organizations. But history and social-technical factors conspire to reduce the role and status of those from whom the experiential knowledge arises, while complexity and pressures for efficiency and risk- and safety-control increasingly remove the conditions under which experience can develop and become applied. Although some organizations have shown a remarkable capacity to adapt and perform in the most demanding environments, there is some concern that 'bottom up' learning is becoming increasingly difficult.

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1. Introduction

The subject of this panel is the influence of technology on organization 'from the bottom up', which leads to the interesting question of what is the 'bottom' and which way is 'up'? What this was intended to convey in the context of this workshop is the influence of technology per se (i.e, the machinery itself) on the organization of work, particularly as shaped by growing technical complexity and increased 'coupling' in the workplace, as contrasted with the 'top-down' formation of organizational practices by institutional values and management policies.[1] A useful distinction. But what is it that sets management cadres at the hierarchical top of the conceptual map and instrumentalities at the bottom, if not the persistence of the industrial class structure of the nineteenth century?

As Jens Rasmussen has pointed out, technological evolution has completely changed the nature of the workplace (Rasmussen, 1988,1989). Where once mechanical and human factors could be clearly separated, and the origins of accident or error assigned either to mechanical/technical or human performance, industrial safety in the modern context involves a number of interactive organizational and design issues that require a better integration of relational and causal analysis.

In analyzing a number of modern techno-industrial 'accidents', James Reason has come up with the fascinating notion of 'resident pathogens' -- systemic factors and tendencies within large, complex, high-technology organizations that carry with them the systemic predilection for errors to occur (Reason, 1988, 1989). His argument and the complementary work of Perrow (1986) suggest that it is not increased technical complexity alone, but complexity combined with tight 'coupling' that produce the situations in which the probability of 'errors' will be greatest.[2]

Understandably, much of the attention given to risk and safety in large-scale technological organizations has arisen from manifest failures, particularly where considerable public harm has occurred (e.g. Bhopal, Chernobyl, *Challenger*). Recently, my colleagues and I have reported research on a small number of organizations managing technologies of comparable potential risk, technical sophistication, and complexity that do manage their operations with a remarkably low rate of error and accident (Rochlin et al., 1987; Roberts and Gargano, 1989). In congruence with the arguments of Rasmussen, we have observed that one of the major differences between these 'high reliability' organizations and others that have failed is the prevalence and support of flexible

[1] Throughout this paper, I avoid using the word 'technology' to describe only machinery or other instrumentalities. That 'technology' is a term that properly encompasses both the instrumentalities and the social organizations that put it to work is a fundamental precept of the research agenda of the Berkeley group. See La Porte, "Technology as Social Organization" (1984).

[2] For a discussion of the difference between complexity and coupling, see Appendix A.

There was, however, a second major pattern that derived from increasing technical complexity. A motor car has far more parts than a wagon; furthermore, the separate parts must fit and work together more closely, and production must be both better coordinated and better controlled. Thus, the second major pattern, which is properly characterized as resulting from intrinsic coupling -- the coupling of technique and process together constituting a more sophisticated and complex 'technology.' This is the branch that is of the most interest to follow.

Neo-Classical Industrialization

In the neo-classical picture of the manufacturing or industrial concern, there were a minimum of three levels of class structure. At the top were the owners and the plant managers who worked for them.[3] Beneath this top structure was an intermediate class with two divisions: the 'white collar' division of financial and administrative officers and the 'blue collar' division of 'shop culture' engineers (who had not, in those early days, fully made the transition to becoming white collar 'managers' as well).[4] Beneath these were the working class of machine operators, clerks, accountants, salespeople, etc., who were more or less equivalent in the eyes of management, whatever the fine class distinctions they made among and between themselves. Between the class layers, serving as buffers, translators, and channels of communication were such intermediaries as foremen, personnel managers, administrative assistants, sales managers, etc.[5]

In this picture, authority and responsibility were assumed to flow from the top down the hierarchy in a classic 'inverted tree' model. Orders and schedules were made at the top, and passed down the chain for execution, with lines of responsibility and authority branching off independently at each node. Of course, the reality was known to be quite different. You could not sell what you could not make; should not make what you could not sell; and could not operate machinery outside its design range or when it was under or in need of repair. Henry Ford ran his managers, and they ran the assembly line as if it were a human-powered automaton, but even Henry couldn't sell a red Model-T, or demand newer models during the era of falling sales, without investing a considerable sum in redesign and reconstruction of the basic machinery of production.

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3 In the early stages of the industrial revolution, 'owners' were likely to have come up through their own industry (i.e., Henry Ford, David Douglass), and therefore to retain a working interest in the firm despite large accruals of wealth. In later stages, owners increasingly became remote from actual operations, leading eventually to firms whose 'ownership' was a combination of public shares and wealthy investors and financiers. This introduces a second element or dimension regarding risk and management that is not followed up on in this paper.

4 To quote Noble (p. 27): "At the turn of the century, the great majority of practicing engineers were still those who had received their training in the 'school of experience' rather than the colleges of engineering. There were in fact ... a distinct traditional 'shop culture' in mechanical engineering and a 'field culture' in civil engineering which were very much in conflict with the 'school culture' of the younger engineers." Of course, the situation was somewhat different in the fields of electrical and chemical engineering, where the transition from shop to school culture was made more completely at an earlier date.

5 Once again in the interests of simplicity and directness of argument I omit the mechanisms by which the interests and status aspirations of working class white collar workers were coopted by management.

The Neo-Classical model amplified: The Assembly Line

The early form of industrial organization may fairly be described as a piecemeal aggregation of individual units. As the nineteenth century turned into the twentieth, industrial organizations in search of greater efficiency sought to avoid 'wasteful' duplication of skill. In the electrical and chemical industries, the entire means of production was radically revised to shift the emphasis from practical to scientific knowledge (Noble, p. 16). In other industries, the workplace was socially reorganized to a form that greatly increase technical and social coupling. In some cases, this involved adoption of 'scientific management' and Taylorism.[7] In others, a less theoretical but more effective technique -- the assembly line -- was devised, and it is this form that I use as a model for the present discussion.

In the classic 'Henry Ford' model of the assembly line, individual tasks were sequenced together tightly by a linkage whose manifestation was mechanical (the 'line'), but whose underlying structure and purpose was manifestly organizational. Organizational 'slack' (i.e., available but normally unused resources) and buffering capacity (resource storage space between or among different tasks to allow for uneven output rates) are relatively expensive, yet are an absolute requirement for a factory based on piecemeal aggregation. One solution to increased productive efficiency is to remove or considerably reduce the need for slack and buffering capacity by first standardizing, and then tightly coordinating and scheduling the individual tasks and suboperations.[8]

As is by now well known from the historical critiques of 'Taylorism' as well as from modern studies, this form of organization tends to alienate workers. Whereas good morale could be built in craft or piecemeal operations through pride in work and/or shared responsibility for overall output, the classic assembly line tends to remove both power and understanding, considerably reducing their perceived status and value.[9] With the advent of the assembly line, each worker was assigned a task so narrow that accumulation of experiential knowledge was essentially irrelevant; the workers task became quite truly only a job to be performed.

Accompanying this was the rise in status of the technical and foreman cadres. Experiential knowledge at the level of production or process was increasingly concentrated in foremen and other intermediate classes, whose overview of production and breadth of task was sufficient to allow accumulation and diversity of experience. At the same time, the increasing shift in importance of the machinery compared to the workers elevated the technical staff, 'whitening' their collars. And, as process sophistication grew, so did the importance, power, and status of the engineers -- with the highly professionalized, management-oriented cadre of 'school trainees'

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[7] As Noble notes: "Although the scientific management movement began within the large corporations ... its origins actually lay outside the corporation, in the fading identity between the engineer and the machine-shop manager and entrepreneur." (p. 40).

[8] The first industry-wide standards movement in America was launched by the Society of Automotive Engineers in 1905. Following World War I, this movement was carried over into the social realm. For example, Dexter Kimball, Dean of Engineering at Cornell University noted: "the extension of the principles of standardization to the human element in production is a most important and growing field of activity." (Noble, p. 83).

[9] Strangely enough, this critique was first formulated around the famous counter-example of Mayo's studies at the Hawthorne plant of Western Electric, where it was found that a worker's productivity was a function of the attention paid to him or her. References from Noble, p. 19.

The development of large-scale technical-industrial concerns was therefore accompanied by a decrease in the status and visibility of those whose knowledge was primarily experiential. This did not mean that they ceased to exist. Indeed, it can be argued that as plant and process grew more complex, the role of experiential knowledge in keeping operations going actually increased. As engineers became more professionalized, their familiarity with operational details decreased; as processes became more sophisticated, the range of competence of individual workers was a decreasing fraction of the whole. At the same time, the role and range of knowledge of those who had been through several changes and understood them actually increased. Thus, the legendary stories of "old Mike" on the plant floor, who could tell a boiler was going to break down by the way it sounded, of "old Harry" in management, who seemed to be able to smell how a certain change would affect sales, or "old Eloise" in accounting, who was the only one who could predict accurately in advance whether operations were to be profitable that quarter.[12]

The very characterization denoted the "declassing" of experiential knowledge, with the implication that "old so-and-so" was a useful tool but, however quaint, hardly more. Why did that not matter more? Although these people played a crucial role in mediating complexity, the coupling was still loose. Their comparative lack of status, power, and decision-making authority mattered little when there was time to pass the information up and down the administrative ladder -- so long as it was eventually acted upon. Although the period of the 'old hand' is now remembered with some nostalgia, and considerable fondness, such people were in rarely well rewarded for their experiential knowledge.

In the nineteen-twenties and thirties, a new class of technologies developed whose intrinsic properties introduced notions of complexity and coupling at a level still only dimly perceived. Perhaps the most visible in those earliest days was the airplane, a technology stunningly unforgiving of errors in either operation or application of technique. Another, still in its infancy, was the networking of electrical power lines into large grids (Hughes, 1983). For these technologies, intrinsic complexity was relatively high, and intrinsic coupling relatively tight. And, for lack of experiential knowledge in the early, exploratory, days, the rate of accidents and incidents was comparatively high. But societies still had relatively low expectations of the performance of these new and 'experimental' technologies; however great the internal task coupling, coupling to the outside world of potential users, the 'environment' was still relatively loose. Only towards the end of the 1930s, for example, were the 'airlines' to systematically reorganize to provide the kind of external reassurance that would draw a wide base of passengers -- in this case actively seeking external regulation.

The Second World War spurred technical development in a number of critical areas, particularly automation, communication, and information processing, and created a number of new 'technological' forms whose **intrinsic** properties, and risks, were eventually to dominate the next phase of technical industrialization.

For a variety of the newly emerging technologies, such as higher-performance aircraft, nuclear power plants, high-performance military systems, extensive and tightly-coupled power grids, and an increasing range of mutli-product, multi-function chemical factories and refineries, the processes themselves were considerably more complex technically than their earlier counterparts, requiring a reorganization of the work into a correspondingly complex structure

12 An apology for the sexism of the characterization, but it is, alas, historically accurate.

their conclusions carry over readily to competence within it. Moreover, it is not only readily observable external changes in process or product that can erode the value of experiential knowledge, thereby destroying organizational competence.

In a number of areas discussed in this workshop and the previous one (Rasmussen and Batstone, 1989), there is concern that gradual transformation of technologies to improve efficiency, and even to demonstrate safety and reduce risk, have introduced so many quantitative changes so quickly that their resultant is a qualitative change in the plant or workplace. Increasing complexity and increasing rates of technical change impose knowledge requirements that are often beyond the capabilities of the 'old hands' to adapt. As a result, a kind of feedback loop has developed in some industries, in which the inability to find a satisfactory range of experiential knowledge upon which to rely spurs the development of elaborate, epsitemically-oriented safety and control systems (often automated and computer-regulated or controlled), whose reliability is in turn analyzed solely upon epistemic and technical grounds for lack of an experiential knowledge base.

It is this type of situation that concerns Rasmussen when he talks of the increasing inability to decompose problems of equipment and of people, or Reason when he discusses the origins of 'resident pathogens.' The substance of my argument here is to point to *phronesis* -- the locus of the experiential -- as the level at which such failures of design and implementation become manifest. Moreover, as the following examples will illustrate, the inability of workers to organize their work situations effectively can be either extrinsic (which allows for some remedial action), or intrinsic (in which case organizational-industrial redesign is probably the only solution). Unlike the cases analyzed by Reason, both of these were relatively harmless, but their simplicity is useful for the purpose of illustration and example.

Two Modern Tales

A few years ago, a colleague of mine decided to extensively remodel his home, and thereby to incorporate into it what was then 'state of the art' residential solar hot water heating -- for space heat, for hot water, and for his swimming pool. Being technically adroit, he negotiated with Philips for the purchase of some advanced thermal solar collectors -- ethylene glycol exchangers in glass tubes about 6 cm in diameter and 2 m long -- and designed an elaborate system of pumps, heat sinks, heat exchangers, and thermostats to collect and distribute the hot water according to demand.

When the time came to put it all together, he was unable to find a contractor anywhere with any relevant experience. And thereby hangs a long and painful tale. Without going into every excruciating detail, suffice it here to note that many contractors, and many workers, simply refused to do things the way they needed to be done. The workers were reluctant to take the responsibility for doing things in a different way, and contractors felt that they lacked the experiential base for assuming the responsibility. As a result, numerous 'errors' and failures occurred. Among them were: the cross-coupling of two collector banks without check valve, so that they formed an oscillator (in this case, an experienced, older mechanical engineer observed that they had 'rediscovered the reciprocating steam engine'); several plumbers who burned their hands picking up collectors tubes that they had left out in the hot sun; and the necessary intervention of my colleague to direct things to make sure they were properly hooked up.

workers as parts rather than resources.[13] But the extensive study of the introduction of information technologies into the workplace by Zuboff (1984) cites many examples of the dangers of the "abstraction of industrial work" that seem to suggest that the phenomena will not be localized to American practice.[14]

As discussed in my previous analysis of the Berkeley group's field research into naval flight operations, system-level interpretation and integration in at least one highly successful high-technology, high-complexity, tightly-coupled operation is performed primarily by the vehicle of carefully nurtured experiential knowledge (Rochlin, 1989). We have made similar observations on other systems we have studied -- air traffic control, utility grid management, and oil-and-gas fired electrical generation -- that also perform highly demanding tasks with considerable reliability and a low rate of serious error.

In all of these systems, considerable effort has also been extended to nurturing redundancy, cultivating extra resources, and building in a capacity to buffer. However, each of these systems is also under some pressure to 'modernize' by installing more advanced technologies that will increase the capability of individual operators to perform their tasks. What operators fear is that an attendant consequence will be to deprive them both of their excess capacity (slack), their ability to learn from small errors how to avoid the large, and sufficient experiential basis to act on 'instinct' when complex, automated systems fail. Thus, although errors may become less frequent, they are likely to be more consequential, once again driving the loop to acquire more technology to reduce the incidence of error still further.

The Effects of Consequentiality

Where consequences are high and trial and error is low, the acquisition of experiential knowledge is difficult, and sometimes expensive. Where technology confers status and professionalization is at a premium, those who rely largely on experiential knowledge are undervalued. And here lies the origin of many of the problems discussed in this series of workshops.

Nuclear power plant operators, who have rarely had to intervene in a truly serious (not simulated) event, have little basis for trusting their actions other than by rote (going by the book) and by consulting their technical assistance (computers and rules). Nor have they much basis for action if an event sequence should go outside the predictive envelope within which the rules are developed. At Chernobyl, there was a considerable amount of confusion, along with a false self-reassurance that things were really not going that badly (*Pravda*, 1988). The workers at Bhopal seem to have applied their own cultural norms in the face of the unexpected, and sat down to

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[13] To quote a summary article: "The American industry of the 1950s and 1960s pursued flexibility by hiring and firing workers who had limited skills rather than by relying on multi-skilled workers. Worker responsibility and input progressively narrowed, and management tended to treat workers as a cost to be controlled, not an asset to be developed" (Berger et al., 1989).

[14] One plant manager quoted by Zuboff said: "We have so much data from the computer, I find that hard drives out soft. Operators are tempted not to tour the plant. They just sit at the computer and watch for alarms. One weekend I found a tank overflowing in digesting. I went to the operator and told him, and he said, 'it can't be; the computer says my level is fine.' I am afraid of what happens if we trust the computer too much." (p 69).

5. Conclusion

For the organizations that our Berkeley research group has studied to date, organizational self-design shaped by task and task environment has played a major role in providing safety and reliability in the face of very demanding circumstances. In every case, there are some elements of organized, systemic design from above (*episteme*), and of practical, task-oriented knowledge from below (*techne*). But in every case, the holders of experiential knowledge, shaped by and conforming to the realities of task and workplace, have played a major role in determining how the organization reacts and responds to crises and other 'out of bounds' events.

It must also be noted, as a word of caution, that in every case these experienced workers had available to them sufficient time to learn their jobs, sufficient allocation of 'excess' organizational resources to put their own ideas and choices into place, and sufficient confidence in their own abilities and experience to challenge managers and professionals in order to get their voices heard. These conditions are neither generalizable nor stable, either in the industrialized countries or among the developing ones.

The traditional importance of practical knowledge of technology is an embedded American tradition (however badly it is put to use in modern industries), shared with and similar to related traditions among the industrialized countries of Europe. If the status of these people is being challenged even among those countries where the tradition is strong, how can we expect to see it develop among those countries where the previous tradition was practically nonexistent?

Moreover, there is a clearly visible trend among the more advanced countries towards removing the conditions under which experiential knowledge evolved to exert leverage over organizational design. As the pace of technological change quickens, dislocations of competence of the sort discussed by Tushman and Anderson will become more common. Some industries will be affected more than others. But which? At the same time, pressures for greater efficiency in an increasingly competitive environment, and for manifest and demonstrable (quantifiable) response to regulatory and public pressures are more and more responded to by the introduction of automation, in forms ranging from simple automatic machine tools or controls through applications of such advanced information and communication technologies as rule-based 'expert' systems.

Although these new technical systems are 'neutral,' in the sense that they can be used to augment and bolster expertise as well as undermine and replace it (Zuboff, 1988), a combination of circumstances -- desire to avoid 'human error,' the high cost of experienced labor, etc. -- seems more often than not to result in the design of systems that have little slack, little buffering capacity, and almost no excess resources. Moreover, the more consequential the results of errors or failures, the greater the pressure to aovid 'human error' by de-humanizing process and procedure. Under such circumstances, experiential knowledge, even if present, has not the resources to nurture and promote organizational self-design and self-modification at the scale we have observed, e.g., in the U.S. Navy.

As David Woods (1987) has pointed out, there will always be a tension between top down design of what is needed and bottom up constraints on its application and practical development. Extending this into the domain of the cognitive, Woods points out the need for exploration of the experiential realm of application, for "a cognitive description of the interaction

Appendix A

Complexity and Coupling in Performance-Demanding Organizations

There is at times some confusion between the terms 'complexity' and 'coupling' owing to their relatively loose usage in common speech. As a general rule, this might not matter, but in the study of organizations seeking highly reliable operations, the distinction is critical. Let us take some simple examples of critical medical care to illustrate the point that the tightness of coupling represents sequencing to task or environment, while complexity represents interconnections between interactive units.

One form of medical delivery service with a high degree of coupling and low complexity is the emergency paramedic team, often associated with the local fire department. The degree of coupling to both task and environment is quite high. In an emergency, the team must get to the site very quickly, so that when on call they are always prepared to respond immediately, and have specialized communications channels to vector them. Task coupling is also very high, especially in life-threatening emergencies. Complexity, however, is relatively low. The teams are small and their interdependence is localized in both space and time.

Another form might be elaborate surgery -- a heart transplant for example. Here the degree of complexity, as measured by the indices of differentiation of task, number of units, and their interdependence, is quite high. Unless all coordinate effectively, the task will be poorly done, if at all. But the coupling may be relatively weak. The operation can be reasonably scheduled, so that people will have time to assemble and think about what they will do next. Moreover, there may even be time during the operation to pause for a bit to think about the sequencing of the next few tasks. And, finally, little in the way of time pressure is applied from the environment.

Most clearly related to 'high reliability' would be the emergency room of a large, urban hospital. Here, the complexity is at least as high as for any scheduled surgery, but it is accompanied by what is often extremely tight coupling both to task and to the environment. Because they know the complexity is high, emergency room staffs are unusually sensitive to the current state of equipment and staffing; because they know the coupling will from time to time be very tight, they are constantly alerted and prepared for it. Moreover, they are constantly drilled to keep the team alert.

Of course, either of the other two cases might suddenly move into the complexity-plus-coupling situation, but in both cases medical teams are generally aware of the prospect. In any major surgery, coupling can suddenly increase -- massive internal bleeding, for example. And in any paramedical emergency, it might be necessary to coordinate in a very complex web of circumstances (the Sioux City DC-10 crash).

The point is that the situations are distinct. What makes some medical services reliability-seeking organizations is the constant awareness of the variability of complexity and coupling, and an accompanying alertness to signals that either, or both, is shifting in a dangerous direction.

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