Unlearning Ineffective or Obsolete Technologies

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Abstract: Often, before they can learn something new, people have to unlearn what they think they already know. That is, they may have to discover that they should no longer rely on their current beliefs and methods. This paper describes eight viewpoints that can help people to do this.

1. Sticking to one's . . . uh . . . depth charges

Starting in the mid 1970s, the Swedish defense forces pursued Soviet submarines lurking off the Swedish coast. Time and again, the Swedes mounted large-scale anti-submarine searches that included the dropping of grenades and depth charges and the detonating of remote-control mines.

For example, in May and June 1988, there were nine live-fire engagements between the Anti-Submarine Warfare unit and suspected foreign submarines. The Swedish Defense Ministry reacted by giving commanders on the scene authority to decide when to open fire. On one occasion, "the prowler was detected and trapped in 282 feet of water . . . about 60 miles south of Stockholm," said a Ministry spokesman. The hunters opened up on the submarine with more firepower than Sweden had used previously. But the hunters lost contact with their prey amid the noise of exploding depth charges and underwater grenades, and the submarine apparently slipped away in the turbulence. "When we played back the tapes, we saw that the submarine was exactly where we thought it was," the spokesman explained. He said "it's probable" that the hunters hit and damaged the submarine although a search had failed to produce evidence of damage. "Our anti-submarine activities have continuously improved."

Dozens of such searches occurred every year, always during the warmer months. Yet none of these searches ended with the capture of a Soviet submarine. Only once, in October 1981, did the Swedes actually capture a Soviet submarine, and in this instance, there had been no hunt by the defense forces. Rather the submarine made a navigation error and grounded on rocks along Sweden's southern coast.

Some people theorized that the Soviets might be seeking spots where they could hide during warfare. Others posited that the Soviets might be testing their submarines' ability to evade detection. Still others speculated that the Soviets might be probing the Swedish antisubmarine defenses. The Soviets consistently denied that their submarines had been anywhere near Sweden, but these denials only reinforced the Swedes' suspicions. In 1982, in a clear reference to the Soviet Union, the chief officer of the navy, Rear Admiral Per Rudbeck, declared that "a foreign power is preparing for war against us".

Sweden's ineffectiveness against the Soviet submarines, although embarrassing, did not surprise them. No one really expected David to defeat Goliath. The Swedes had never intended their navy to command respect as a military power, whereas the Soviet navy was renowned for its skill and technology.

Then in February 1995, Sweden's defense chief Owe Wiktorin told a news conference that the Swedish navy had acquired new hydrophonic instruments in 1992, and these had shown that minks give off sounds similar to submarines. Earlier equipment had identified the sounds as submarines, he said, but there may never have been Soviet submarines lurking off the Swedish coast. "The intruding submarines were not submarines but minks, or at least most likely minks." Wiktorin said the Defense Ministry was certain that no foreign submarines had intruded into Sweden's territorial waters since 1992; defense analysts were

checking sound recordings of suspected submarines from before 1992 to see if the sounds were really just small animals like minks and otters swimming from island to island. Eventually, Wiktorin reported: "There is overwhelming evidence (technical, acoustical, and visual) that there have been five foreign submarine operations on Swedish territory since 1981," including the Soviet submarine that ran aground in 1981.

That the navy might pursuing animals had been proposed as early as July 1987. After the navy had dropped depth charges and fired anti-submarine grenades unsuccessfully for almost three weeks in search of foreign intruders, Tero Harkonen, a Swedish seal expert, speculated that the anti-submarine hunt had been triggered by the play of young seals. "They can play, gush through the water, and even create foam on the surface," he explained. However, navy officials maintained that the navy had surrounded a foreign mini-submarine or another type of underwater vessel with nets. They declared that there had been many "reliable" sightings of suspected alien submarines and submarine activity in the area over the preceding two months, including air bubbles from a diver. The navy continued searching and dropping depth charges for another ten days before giving up the effort.

The Swedish Defense Ministry's recognition of error was partly the result of a change in government: A different political party had control in 1995. The recognition was also partly a result of the dissolution of the Soviet Union. The Soviet Union had collapsed, and its no-longer-so-secretive remnants no longer seemed capable of the remarkable underwater feats that the Swedes had been attributing to them. Indeed, during their 1995 review of earlier antisubmarine hunts, the Swedes consulted Russian antisubmarine experts. The Russian experts, the Swedes reported, agreed that the Swedes had been pursuing submarines but denied that the submarines had been Soviet ones.

This story illustrates three points. First, learning often cannot occur until after there has been unlearning. Unlearning is a process that shows people they should no longer rely on their current beliefs and methods. Because current beliefs and methods shape perceptions, they blind people to some potential interpretations of evidence. As long as current beliefs and methods seem to produce reasonable results, people do not discard their current beliefs and methods (Kuhn, 1962). As Henry Petroski (1992: 180-181) put it: "Technologists, like scientists, tend to hold onto their theories until incontrovertible evidence, usually in the form of failures, convinces them to accept new paradigms." Indeed, the Swedish navy shows that people may adhere to their current beliefs and methods despite very poor results. Even after two decades of abject failure, the leaders of the Swedish navy continued to construe their organization's failures as the logical result of an amateurish defense force from a small country competing against a highly sophisticated defense force from a large country.

Surprisingly perhaps, technical experts may be among the most resistant to new ideas and to evidence that contradicts their current beliefs and methods. Their resistance has several bases. Experts must specialize and their specialized niches can become evolutionary dead-ends (Beyer, 1981). Because experts' niches confer high incomes and social statuses, they have much to lose from social and technical changes. Expertise creates perceptual filters that keep experts from noticing social and technical changes (Armstrong, 1985). Even while experts are gaining perception within their domains, they may be overlooking relevant events just outside their domains.

Second, organizations make it more difficult to learn without first unlearning. People in organizations find it hard to ignore their current beliefs and methods because they create explicit justifications for policies and actions. Also, they integrate their beliefs and methods into coherent, rational structures in which elements support each other. These coherent structures have rigidity that arises from their complex interdependence. As a result, people in organizations find it very difficult to deal effectively with information that conflicts with their current beliefs and methods. They do not know how to accommodate

dissonant information and they find it difficult to change a few elements of their interdependent beliefs and methods. The Swedish sailors who conducted the searches had been trained to interpret certain sounds as a submarine and rising bubbles as a diver; they had not been prepared for the sounds and bubbles made by animals. A Swedish navy that had just spent three weeks dropping depth charges and antisubmarine grenades in the belief that it had trapped an intruder was not ready for the idea that it had been deceived by playful young seals.

Tushman, Newman, and Romanelli (1986) characterized organizations' development as long periods of convergent, incremental change that are interrupted by brief periods of "frame-breaking change." They said "frame-breaking change occurs in response to or, better yet, in anticipation of major environmental changes." However, even if abrupt changes do sometimes "break" people's old perceptual frameworks, the more common and logical causal sequence seems to be the opposite one. That is, people undertake abrupt changes because they have unlearned their old perceptual frameworks.

Third, unlearning by people in organizations may depend on political changes. Belief structures link with political structures as specific people espouse beliefs and methods and advocate policies (Hedberg, 1981). Since people resist information that threatens their reputations and careers, it may be necessary to change who is processing information before this information can be processed effectively. Thus, a change in control of the Swedish government may have been essential before the Defense Ministry could concede the possibility of errors in the conduct of antisubmarine hunts. A change in control of the Soviet Union may have been essential before the Swedes could allow the possibility of Russian vulnerability or truthfulness.

Top managers' perceptual errors and self-deceptions are especially potent because senior managers can block actions proposed by their subordinates. Yet, senior managers are also especially prone to perceive events erroneously and to overlook bad news. Although their high statuses often persuade them that they have more expertise than other people, their expertise tends to be out-of-date. They have strong vested interests, and they know they will catch the blame if current policies and actions prove wrong (Starbuck, 1989).

There is, of course, every reason for people to suspect that current beliefs and methods are wrong. Not only do new discoveries convert good current beliefs and methods into no-longer-good, but there is normally no reason to trust that current beliefs and methods ever were good. The QWERTY keyboard provides an on-going reminder of the persistence of poor methods (Gould, 1986). Although C. L. Sholes had reasons for placing the keys in particular positions, he designed QWERTY for a machine that differed considerably from modern typewriters. The widespread adoption of QWERTY was fostered by a highly publicized contest between two typists in 1888. Frank E. McGurrin, the typist who used QWERTY, won by a large margin. But McGurrin had memorized the keyboard and could type without looking at his fingers whereas his competitor had to look at his keyboard in order to find the right keys.

2. How People Can Foster Unlearning

"There is not the slightest indication that [nuclear] energy will ever be obtainable. It would mean that the atom would have to be shattered at will." Albert Einstein, physicist, 1932.

Einstein later wrote to President Roosevelt to urge that the United States attempt to construct an atomic bomb.

This article suggests ways to facilitate unlearning. Since the essential requirement for unlearning is doubt, any event or message that engenders doubt about current beliefs and methods can become a stimulus for

unlearning. There are at least eight viewpoints that can help people turn events and messages into such stimuli. People can start from the premises that current beliefs and methods are "not good enough" or "merely experimental." They can turn surprises, dissents, and warnings into question marks. They can listen carefully to the ideas of collaborators and strangers. They can look for feedback paths and they can try to synthesize divergent interpretations of phenomena.

"It isn't good enough."

Dissatisfaction is probably the most common reason for doubting current beliefs and methods. But dissatisfaction can take a very long time produce results.

Robert Fulton launched the first commercially successful steamboat in American waters in 1807 (Petroski, 1996; Ward, 1989). In 1816, the boiler on a steamboat exploded and injured or killed nearly all of the boat's crew. Over the next thirty years, boilers exploded on 230 American steamboats. Thousands died; more were maimed.

Some people said these explosions were "acts of God;" others attributed them to demons in the boilers; still others theorized that high temperatures decomposed water into hydrogen and oxygen, which then recombined explosively. In 1824, the inventors and mechanics of Philadelphia formed the Franklin Institute and this Institute sought to study the causes of boiler explosions. By 1830, boiler explosions had become the Institute's highest priority, but it lacked the funds to conduct experiments so it sent out questionnaires. However, a particularly bloody explosion in 1830 induced Congress to ask the Secretary of the Treasury to investigate, and he granted funds to the Franklin Institute. This $1500 was the first research grant awarded by the U.S. government. The Institute's experiments disproved some theories about boilers and showed some unexpected effects. It submitted a report on explosions to Congress in 1836 and a report on boiler materials in 1837.

In April 1838, a steamboat exploded and killed about 200 people, which motivated Congress to pass the Steamboat Act of 1838. Unfortunately, the law required inspection of boilers but it did not provide inspectors and it did not require that a steamboat be removed from service if it failed an inspection. Many more steamboats exploded. Finally, in 1852, Congress set up a regulatory agency with enforcement powers.

But the legislation and the regulatory agency focused solely on steamboats, although boilers had also been exploding in factories. Indeed, there were several hundred boiler explosions annually and they continued into the twentieth century. The worst was a steamboat explosion that killed 1200 to 1500 people in 1865. However, by the mid 1880s, there was general understanding that the explosion were due to excessive pressures, defective materials, or inadequate or malfunctioning equipment.

"It's only an experiment."

People who see themselves as experimenting are willing to deviate temporarily from practices they consider optimal in order to test their assumptions. When they deviate, they create opportunities to surprise themselves. They also run experiments in ways that reduce the losses failures would produce. For instance, they attend carefully to feedback. They place fewer personal stakes on outcomes looking successful, so they can evaluate outcomes more objectively. They find it easier to alter their beliefs and methods to allow for new insights. They keep on trying for improvements because they know experiments rarely turn out perfectly.

For example, in 1964, 3M corporation began an exploratory research program to develop new adhesives.

Spencer Silver, one of the chemists working on this project, later explained: "In the course of this exploration, I tried an experiment to see what would happen if I put a lot of it into the mixture. Before, we had used amounts that would correspond to conventional wisdom. . . . If I had sat down and factored it out beforehand, and thought about it, I wouldn't have done the experiment. If I had really cracked the books and gone through the literature, I would have stopped. The literature was full of examples that said you can't do this notepads" (Nayak & Ketteringham, 1986: 57). The result was that Silver found a radically new adhesive: It sticks to surfaces without bonding tightly so it removes easily without leaving traces. It was so unusual that Silver and others at 3M had great difficulty seeing how it could be applied usefully. But it eventually spawned an important new product line: Post-It note pads.

"Surprises should be question marks."

Events that violate expectations, both unpleasant disruptions and pleasant surprises, can become opportunities for unlearning. For instance, the Allies developed the tank during World War I, and most army officers viewed the tank as lethargic support for the infantry (Fleming, 1995). However, George S. Patton, the commander of an American tank unit had trained as a cavalryman and he saw the tank as being able to perform the cavalry function of reconnaissance. At battle of St.-Mihiel, a wide no-man's land developed and Patton ordered a three-tank patrol to advance until it found the enemy lines. When German cannons fired on the patrol, its commander, Ted McClure, ordered his tanks to charge, with the result that they routed the Germans and destroyed the cannons. This provided a conceptual breakthrough for Patton, and subsequently other army officers, by showing that tanks could make daring attacks.

Marcie Tyre and Wanda Orlikowski (1994) studied technological adaptation in production processes. Sixty percent of the adaptation occurred during the first 2.5 months after the introduction of new processes, but 23 percent of the adaptation occurred during a second 2.4-month spurt that started about eleven months after the introduction of new processes. These later spurts were initiated by events -- such as new equipment, new production requirements, or new personnel -- that disrupted routine operations and stimulated new thinking about the technology and its use. It took disruptions to induce rethinking because users rapidly came to accept the deficiencies and inadequacies of new technologies.

Too often, however, the analyses following disruptions extend only to the immediate causes of the specific disruptions. If disruptions are to affect unlearning strongly, people need to use them to reveal weaknesses in their current beliefs and methods as well as to stimulate improvements. Why didn't the original designs anticipate the events that caused disruptions? Would organizational changes or different engineering concepts have fostered more robust designs?

The North American power grid seems to illustrate ineffective unlearning. In 1964, the U. S. Federal Power Commission stated that the North American electric-power grid could deal effectively with a nuclear attack (Chiles, 1985). On November 9, 1965, one of Toronto's power stations began having minor mechanical difficulties, so Toronto began drawing more power from a station at Niagara Falls. A relay at the Niagara Falls station incorrectly sensed an overload and disconnected the overloaded transmission line from the power grid. This switched 375 million watts onto four other lines that were already near capacity. They too disconnected, so 1.5 billion watts flowed onto two lines that fed into northern New York. This power surge disconnected another connection between the U. S. and Canada, so Ontario was both short of power and unable to receive it. Circuit breakers clicked open throughout the eastern U. S. and separated the power grid into subsystems. In a few areas, the resulting blackouts lasted less than fifteen minutes. In New York City, the blackout lasted thirteen hours. Although New York City had enough generating capacity not only to sustain itself but to supply power northward, the human dispatcher did not push the right eight buttons quickly enough. Many generators were very difficult to restart after all power had shut down because starting them required external electric power.

The blackout evoked controversy. Some argued that an integrated power grid was inherently faulty; utilities should have weak ties to prevent disruptions from cascading. Others argued that strong ties enable utilities to accommodate disruptions, so the ties should be strengthened and the grid expanded. The advocates of stronger ties carried the day. Electric power companies organized into nine "reliability regions", and much control was transferred from humans to automatic systems.

However, in June 1967, an overloaded transmission line in Pennsylvania initiated the second biggest blackout, which affected 13 million people in four states. More procedural improvements followed, but stronger ties have called for more complex control equipment that has been more likely to fail or to produce unexpected results. Wider-scale integration has meant that events can have consequences thousands of miles away. There were more power outages during 1976 than during any previous year. Then on July 13, 1977, lightning hit Consolidated Edison's transmission lines several times in a few minutes, another human operator made another mistake, and New York City again blacked out. More procedural improvements followed, but there were more power outages during 1981 than during any previous year.

"All dissents and warnings have some validity."

It is, of course, not literally true that every dissenter is right or that every warning should be taken seriously. There are a few loonies out there. But, for each loony, there are dozens of sensible people who see things going wrong and try to alert others. Listeners need to guard against hasty rejections of bad news or unfamiliar ideas. At a minimum, dissents and warnings can remind people that diverse viewpoints exist and that their own beliefs and methods may be wrong.

Organizational hierarchies tend to block dissents and warnings. Lyman Porter and Karlene Roberts (1976) reviewed studies indicating that people in hierarchies talk upward and listen upward. They send more messages upward than downward, they pay more attention to messages from their supervisors than to ones from their subordinates, and they try harder to establish rapport with supervisors than with subordinates. The messages that do get through enhance good news and suppress bad news (Janis, 1972; Nystrom and Starbuck, 1984). This bias becomes problematic because bad news is much more likely to motivate people to change than is good news (Hedberg, 1981).

Elting Morison (1966) recounted how by the U.S. Navy learned to shoot much more accurately. In 1899, many gunners on five ships fired at the hulk of a ship for five minutes and achieved only two hits. Six years later, a single gunner fired at a small target for one minute and made fifteen hits.

This improvement came from the efforts of Percy Scott, William S. Sims, and Theodore Roosevelt. Scott, a British naval officer, developed aiming techniques, gun sights, and gears that greatly enhanced gunners' accuracy. Sims, an American naval officer, met Scott, learned of his improvements, and tried them on his own ship. Impressed by the results, Sims then began to write reports to naval bureaus in Washington. First, the naval bureaus ignored Sims' reports. Then, using incorrect logic and contrived data, the Bureau of Ordnance rebutted Sims' reports. They proved with mathematics that Sims' methods could not possibly work even though he, Scott, and other officers were using them. After two years of this rejection, Sims wrote to President Theodore Roosevelt. Roosevelt listened and appointed Sims the Inspector of Target Practice. In this position, Sims taught the U. S. Navy to shoot.

How can people decide whether to take dissents or warnings seriously? Four rules seem sensible. First, assume that all dissents and warnings are at least partially valid. Second, try to find evidence, apart from the messages' contents, about the odds that messages might be correct. For instance, do the sources of

the messages act as though they truly believe what they say? Are these sources speaking of topics with which they have experience? Third, evaluate the costs or benefits that would accrue if messages turn out to be correct. Fanciful messages typically entail high costs or high benefits; realistic messages likely entail low costs or low benefits. Thus, it is the fanciful messages that most deserve attention. Fourth, find ways to test the dissents and warnings that might bring high costs or high benefits. Make probes to confirm, disconfirm, or modify the ideas.

"Collaborators who disagree are both right."

Beliefs held by qualified observers nearly always have foundations in some sort of truth. The most common problem is not to prove that one set of beliefs is wrong but to reconcile apparent contradictions by showing that they are not contradictions at all. These efforts can lead everyone to new conceptualizations. They can also produce some strange inversions.

In 1937, Hannes Alfvén wrote a theory about the origin of cosmic rays (Alfvén, 1985). Showing that cosmic rays could be caused by electromagnetic effects around double stars, he pointed out that the known electromagnetic effects are not strong enough to fill the entire universe with cosmic rays. Thus, he conjectured, cosmic rays must arise in and be confined to a single galaxy. When Alfvén's paper was rejected by the most prominent physics journal, he wondered if this was because the generally accepted view at that time was that cosmic rays filled the entire universe. He published the paper in a much less visible journal.

In 1948, Alfvén attended two lectures in which Edward Teller argued that cosmic rays must arise in and be confined to one solar system. Alfvén struck up an argument with Teller, and Teller responded by inviting Alfvén to present his theory in Chicago. Alfvén went to Chicago, but by the time he arrived there, he had decided that Teller was right. Alfvén and Teller co-authored a paper about the confinement of cosmic rays to one solar system, and Alfvén went on to publish more articles and a book about this theory.

After a few years, Teller changed his mind. He and almost everyone else in astrophysics came around to agreeing with Alfvén's original theory that cosmic rays must arise in and be confined to a single galaxy. Alfvén won the 1970 Nobel Prize in Physics partly for his early work on this topic. But Alfvén himself did not believe in his single-galaxy theory: He continued to believe the theory Teller had originated that cosmic rays arise in and are confined to one solar system.

"What does a stranger think strange?"

It is usually easier to respect the views of collaborators than those of strangers. Unfamiliar with current methods and unacquainted with recent efforts, strangers are likely to make suggestions that seem naïve or ignorant or foolish. Yet, new people often introduce new perspectives. Although the newcomers may be less expert than their predecessors, they are also free of some expectations that their predecessors took for granted. Thus, strangers may be able to see peculiarities that the indoctrinated cannot see or they may be able to offer breakthrough suggestions. Indeed, "reengineering" seems to be designed to exploit this principle (Hammer and Champy, 1993).

During the 1970s, the Sony Corporation produced a small, portable, monaural tape recorder (Nayak and Ketteringham, 1986). It was named the Pressman because Sony expected reporters to use it to record interviews. In 1978, the engineers who had developed the Pressman tried to upgrade it to stereo sound. They succeeded in squeezing the components needed for stereo playback into the Pressman's chassis. But there was no room left for recording components, so the engineers were left with a recorder that could

not record. Of course, a stereo Pressman would also have needed a second microphone and second loudspeaker, presumably on extension cords. Unsure what to do, the engineers dropped the project and used the unsuccessful prototype to play background music in their laboratory.

Sony's founder in 1946 had been Masaru Ibuka. Although Ibuka had retired, he was called Sony's Honorary Chairman and he had the habit of occasionally roaming around the laboratories and factories. One of these tours took Ibuka into the laboratory where the tape recorder engineers were playing their unsuccessful prototype. "And then one day, into our room came Mr. Ibuka, our Honorary Chairman. He just popped into the room, saw us listening to this, and thought it was very interesting." Ibuka said he thought the small box was producing excellent sound. He suggested to the engineers if they had considered producing a machine that had no recording capability. Also, he: suggested, if the machine had no speaker, its batteries would last much longer. He had just visited another Sony laboratory where someone had developed very small headphones that might be mated to this non-recording recorder.

Engineers and managers in both the tape recorder division and the headphone division saw no merit in Ibuka's idea. A tape recorder that lacked both a speaker and recording capability was no recorder at all, so no one would buy it. Headphones were merely a supplement to loudspeakers; if a device had only headphones, only one person could listen.

Undeterred, Ibuka went to Sony's real Chairman, Akio Morita, and said: "Let's put together one of these things and try it. Let's see how it sounds." Morita could hardly refuse such a small request from his company's founder and his friend of many years. So a machine was assembled, and both Ibuka and Morita liked the way it sounded. They began carrying it with them wherever they went - on trips, to play sports -- to see how much they liked it.

Morita decided that Sony should put the Walkman into production. This made the managers of the tape recorder division quite unhappy because, as they saw it, they were being ordered to produce an ineffective device that would almost certainly lose money. With the new lightweight headphones, it would cost $249. Not only was this more expensive than tape recorders with speakers that could record, but the expected teenage consumers could not possibly spend more than $170. The marketing managers said bluntly, "This is a dumb idea." Morita declared that the price would be $165, and he told the tape recorder division to make 60,000 of them.

The managers of the tape recorder division judged that they were being commanded to lose $35 per unit sold. "There was no profit. The more we produced, the more we lost." They secretly decided to produce only 30,000 units and they allotted marketing a budget of only $100,000.

Sony sold almost no Walkmans during the first month after the product's introduction. Then sales picked up, and during the third month, sales rocketed . . . until Sony ran out of inventory. That was when Morita found out that the tape recorder division had produced only 30,000 instead of 60,000. The tape recorder division quickly corrected its error. Six months after the product's introduction, Sony was producing and selling 30,000 units per month.

During the fourth month after the Walkman's introduction, Sony began designing the Walkman II - much smaller, with better sound and longer battery life. Sony planned its production for 200,000 units per month.

"All causal arrows have two heads."

People can use thought processes that tend to disclose and challenge their tacit assumptions. One useful

heuristic is to insist that all causal paths carry influence in both directions: Whenever one perceives that A affects B, one should also look for ways in which B feeds back and affects A. There are some causal paths that do not carry influence in both directions. However, one-directional causation is rare because systems that can converge toward equilibrium have to entail feedbacks. Searching carefully for these feedback paths can lead one to see previously overlooked causal paths.

For example, Toyota developed the concept of a Just-In-Time inventory system by inverting the causal flow. In the traditional view, production converts raw materials into finished goods. A plant turns raw materials into components that feed into in-process inventories, and the plant produces finished products by drawing components from inventories. The finished products go into finished-goods inventories, not directly to customers. Customers must buy from the finished-goods inventories. Thus, analysts view production as flows of materials through stages of conversion; inventories uncouple these consecutive stages.

According to Toyota's Taiichi Ohno, "we reversed our thinking and considered the production process in terms of backward flow" (Nayak and Ketteringham, 1986: 210). What flows backward is information about customers' desires. When customers select finished products, they create vacancies in the finished-goods inventory. As finished products fill these vacancies, they remove components from the in-process inventories. The inventory vacancies created by withdrawn components convey information about the finished products that customers want. The inventory vacancies cascading through the production process automatically decompose customers' desires into components and ultimately raw materials.

Inverting the causal flow led Ohno to see production as the conversion of customers' preferences into demands for components and raw materials. In this view, in-process inventories become barriers that delay the flows of information. To speed this information flow, Toyota set out to minimize its in-process inventories.

"The converse of every proposition is equally valid."

Dialectic reasoning is a generalization of two-directional causation. Starting from a proposition (A affects B), one states the converse proposition (B affects A) and then one insists that both the original proposition and its converse are valid. The philosopher Georg Hegel, who advocated this mode of reasoning, called the original proposition the thesis, its converse the antithesis, and their union, the synthesis. As with causal paths, not every thesis has a valid antithesis and not every thesis can be synthesized with its antithesis. But it is possible to apply dialectic reasoning to almost all situations and the process of applying it helps one to break free of tacit assumptions.

One can see dialectic reasoning in the work of Gideon Sundback, who invented the zipper (Friedel, 1994). During the latter part of the nineteenth century, the most common method of fastening shoes was hooks and eyes. These were also used to fasten women's skirts and men's trousers. But fastening them was slow work and they did not stay fastened very well. The first zipper-like patents, which emerged in 1893, proposed that a sliding "guide" could mate hooks and eyes. These devices were rather complex and they required precise assembly, so around 1904, their inventors began attaching them to cloth tape that could be sewn into shoes or clothing. The design, however, did not work well in that the hooks and eyes tended to separate when the fastener was bent or twisted.

The company that manufactured these devices hired Gideon Sundback to improve their design. His first effort, although better than its predecessors, had similar deficiencies and it was a commercial failure. Around 1912, after pursuing improvements in the prior design for six years, Sundback came up with a

radically different design. In it, a slide forced the beaded edge of a cloth tape between two rows of metal clamps - somewhat like a Ziploc fastener. Thus, Sundback had replaced the proposition 'a fastener involves hooks and eyes' with its antithesis 'a fastener has neither hooks nor eyes.'

The antithetical design also had serious deficiencies -- the cloth tape wore out after only a few uses. But optimistic backers formed a new Hookless Fastener Company, and Sundback continued his experiments. In 1913, he produced a design very like the modern zipper. In it, the hooks had shrunk to small protrusions and the eyes had closed until they were indentations. It synthesized hooks and eyes with their absence, and it synthesized hooks with eyes. The two sides of the fastener were composed of identical elements.

Theories of leadership afford an example of dialectic processes operating on a large scale (Webster & Starbuck, 1988). Early in the twentieth century, most managers and management theorists asserted that organizations work best if they have firm superiors and obedient subordinates. Some fortunate people, it was said, had inherent traits that made them good leaders whereas the less fortunate did not.

By the 1930s, this orthodoxy had elicited counter arguments: Barnard argued that authority is something that subordinates grant rather than something that superiors impose. Weber pointed out that organizations may depersonalize leadership and that subordinates may think their superiors lack legitimacy. The Hawthorne studies presented evidence that subordinates produce more when they have friendly superiors.

Syntheses emerged during the 1950s. Some psychologists studied democratic leadership; others documented the sharing of leadership tasks among members of work groups; and still others analyzed the distinctive personalities of different kinds of leaders. Bales distinguished leaders' social roles from their task roles. Then the Ohio State leadership studies decomposed subordinates' perceptions of their superiors into two statistically independent dimensions - initiating structure and consideration. Initiating structure embodied the essential properties of the leadership concepts of 1910, and consideration embodied the concepts of the 1930s. Thus, antithetical views had become distinct dimensions of a complex phenomenon.

3. Reprise

"I think there is a world market for about five computers." Thomas J. Watson, President, International Business Machines, 1943.

Watson later helped his son lead IBM's expansion in computers.

No one should be confident that their current beliefs and methods are optimal. Optimality is unlikely. If beliefs seem accurate, someone else is probably finding other beliefs equally effective. If methods seem excellent today, better methods will appear tomorrow. Thus, one is well-advised to remain ever skeptical. "It isn't good enough" and "It's only an experiment" are mental frameworks that help one stay constantly alert for opportunities to improve. "It isn't good enough" reminds one to look for more accurate beliefs or better methods. "It's only an experiment" helps one to feel less committed to current beliefs and methods.

Because current beliefs and methods bias information gathering, signals from one's environment tend to support these beliefs and methods. To obtain dissonant signals, one may have to be proactive. Thus, one should try to turn surprises into question marks, should respond to dissents and warnings as if they have some validity, and should act as if collaborators' ideas are as deserving as one's own.

It may be difficult to respect the views of strangers unversed in current methods and unfamiliar with recent efforts. But strangers can see errors or opportunities to which the indoctrinated are blind.

One wanting to challenge current beliefs and to discover alternative methods can apply two logical techniques. "All causal arrows have two heads" helps one to look for neglected feedback paths. "The converse of every proposition is equally valid" helps one to reframe current beliefs within more general schemata.

"There is no reason for any individual to have a computer in their home." Ken Olson, President, Digital Equipment Corporation, 1977.

Five years later, DEC began to sell microcomputers.

Note: This article benefits from the insights of Raghu Garud, John Hedberg, and John Mezias.

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