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Breakthrough and Continuous Improvement in Research and Development—An Essay

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Some of the greatest resistance to TQM's emphasis on the practices of continuous improvement comes from those who worry that continuous improvement is incompatible with the breakthrough needs of our companies, particularly in the area of research and development. I believe continuous improvement in research and development is compatible with breakthrough and is in many cases essential to it.

Although the rest of this essay will primarily consider continuous improvement and breakthrough in the context of research and development, the arguments are probably equally valid for the company at large.

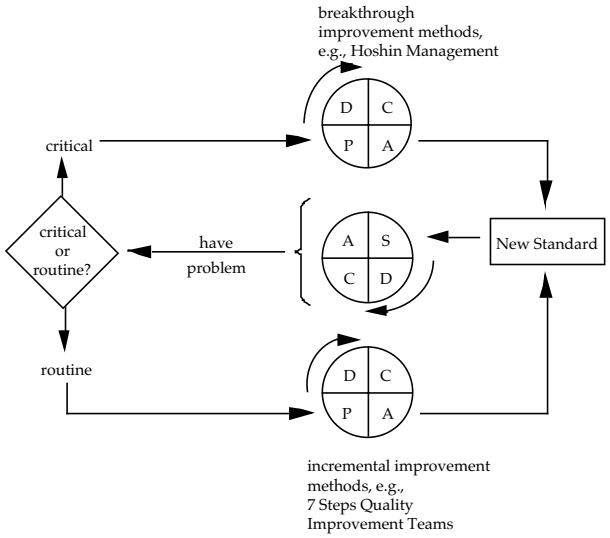
Continuous Improvement Does Not Necessarily Mean Small Improvement

The first objection we hear to breakthrough *and* continuous improvement in research and development usually comes from people who equate breakthrough to innovation and creativity—creating new things—and who equate continuous improvement to small changes to existing processes. In my view, these are false equations.

Continuous improvement does not mean only repeated small improvements. *Continuous improvement means repeated improvements of any size.* In our companies we need repeated, or continuous, breakthrough improvements for our critical systems or products, and we need small, incremental improvements to existing processes. Some Japanese companies that practice TQM explicitly show the two kinds of improvement as part of their continuous improvement system, as shown in figure 1.

The SDCA (Standard-Do-Check-Act) loop in the center of the figure shows the company's standard processes. If the Check and Act steps reveal a problem, the company determines whether the problem is "routine," i.e., requiring incremental improvement of an existing process, or is "critical," i.e., requiring a breakthrough improvement. Problems requiring incremental improvement are handled by the company's incremental improvement methods, such as 7-Steps Quality Improvement Teams, indicated by the PDCA (Plan Do Check Act) cycle at the bottom of the figure. Problems requiring breakthrough are handled by the company's breakthrough improvement methods, such as Hoshin Management, indicated by the PDCA cycle at the top of the figure.

Breakthrough and incremetal improvement systems



Source: Kozo, Koura, *Total Quality Control*, vol. 42, no. 3, March 1991, p. 273.

Figure 1

The words "continuous improvement" do not in and of themselves preclude innovation, creativity, and breakthrough. We need continuous or repeated innovation, creativity, and breakthrough as well as continuous incremental improvement.

Breakthrough and Incremental Improvement Are Not Incompatible

Having sorted out that breakthrough and incremental improvement are two parts of continuous improvement, the second objection we frequently hear is to the idea that breakthrough and incremental improvement can coexist. This objection runs along the lines that if we do incremental improvement in research and development, we can't or won't be effective at breakthrough improvement. This argument strikes me as spurious—a debating trick—pitting breakthrough and incremental improvement against each other as if they are mutually exclusive. They are not. Hayakawa calls this "two-value thinking"—"the assumption, frequently unexamined, that every question has two sides—and only two sides."[1]

[1] S. I. Hayakawa and Alan R. Hayakawa, *Language in Thought and Action*, 5th edition, Harcourt Brace Jovanovich, 1990, chapter 11.

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An easy way to demonstrate that incremental improvement is not incompatible with breakthrough is to remember that little things, the kind that incremental improvement might eliminate, can prevent breakthrough. All of us in research and development have experienced such little things: accounting systems that make use of test equipment so expensive that we are motivated to minimize testing, incompatibility between computer-aided-design systems in engineering and manufacturing, old or weak computer-based simulation and debugging tools, one component in a system whose design is no good, lack of colocation of the project team, ambiguous or changing product specifications, or leaving no slack in the development schedule for unplanned eventualities. Any little incremental thing seems capable of delaying or preventing the breakthrough we are seeking.

Frequently examples of small things that can prevent breakthrough, such as those just given, are examples of weak process preventing breakthrough in the application area, as in development of a new product. This suggests another way of looking at the compatibility of incremental improvement and breakthrough: incremental improvements in the *process* are compatible with breakthroughs in the *application area*. Kaoru Ishikawa drew the diagram shown in figure 2, which is useful for illustrating this idea.[2]

Japanese vs. Western approaches to activities between breakthroughs

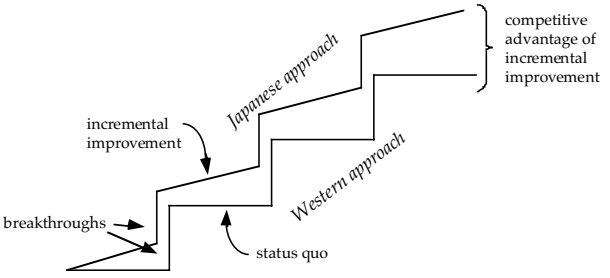

Figure 2

Ishikawa's figure shows our western approach as alternating breakthrough and status quo, consistent with the idea that if we have breakthrough, we can't have incremental improvement. His figure shows the Japanese approach as alternating breakthrough and incremental improvement, which the Japanese believe are compatible. The figure shows that since both approaches include breakthrough, incremental improvement, not breakthrough, is the competitive advantage of the Japanese approach. In other words, incremental process or product improvements between big product breakthroughs provide the competitive advantage.

By treating incremental improvement as incompatible with breakthrough, we lose to those who are using *both* incremental improvement and breakthrough in synergistic ways.[3]

Incremental Improvement Is Frequently the Means of Breakthrough

Incremental improvement and breakthrough are far from incompatible. In fact, incremental improvement is frequently the means of breakthrough. One example of this comes from the Japanese approach illustrated in Ishikawa's figure shown in the left column. The Japanese are using the profits resulting from the competitive advantage they get from incremental improvement to do research on how to innovate systematically.[4]

As noted earlier, incremental process improvements frequently provide better and sharper tools, which then become the means of breakthrough in the application area. When people in research and development hear about process, however, they all too often immediately extrapolate to the kind of complete rigidity that would stifle innovation and creativity. This is another example of fallacious two-valued thinking, as figure 3 shows.

The trade-off between too little and too much process

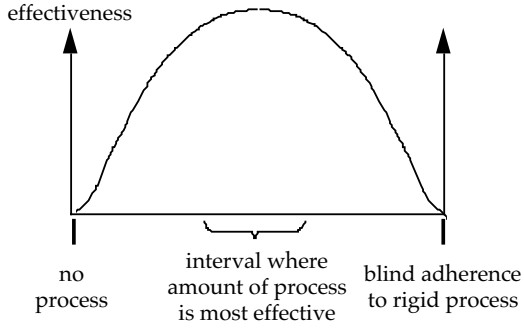

Figure 3

The vertical axes in the figure indicate effectiveness of our research and development efforts. At the left end of the horizontal axis is the point of no process. Most people would agree that having no process is not particularly effective. With no process we never do things the same way twice, we have no vocabulary with which to talk to each

[2] Kaoru Ishikawa, *Introduction to Quality Control*, 3A Corporation, 1990, p. 70. Please note: I have changed the labels on Ishikawa's figure to match the notation used in this essay.
[3] See also Richard Florida and Martin Kenney, *The Breakthrough Illusion*, Basic Books, 1990.
[4] Sheridan M. Tatsuno, Created in Japan, Harper Business Books, 1990; James P. Womack, et al., *The Machine That Changed the World*, Harper Business Books, 1990.

other, and we have nothing to try to improve. Most people would also agree that there is a point at the right end of the horizontal axis, which I have labeled "blind adherence to rigid process," where we have too much process to be effective. Thus, there is a region somewhere between the left and right ends of the process spectrum where we have the amount of process that is most effective—enough to make improvements and maintain them but not so much that things ossify. Processes taught as part of TQM fall in this middle ground. For instance, the 7-Steps and Quality Function Deployment processes provide guidelines for improve- ment that have been proven through experience to be efficient but that every team or person applies as appropriate to the problem they are working on. In other words, these tools require or bring out creativity on the part of those who use them.

Finally, from my experience of over 25 years of participation in and observation of high-technology research and development and my reading about other fields, I have concluded that "breakthrough" is almost always a feeling of climax or appearance of great change that has resulted from extended incremental efforts. We have all read stories in the popular press about the "overnight" success of entertainers, performing artists, craftspeople, or athletes who in fact have worked hard and struggled for years before their popular "breakthrough."

Imagine a person boring through a thick concrete wall with a hammer and chisel (figure 4).

Breakthrough is when the result of the work becomes apparent

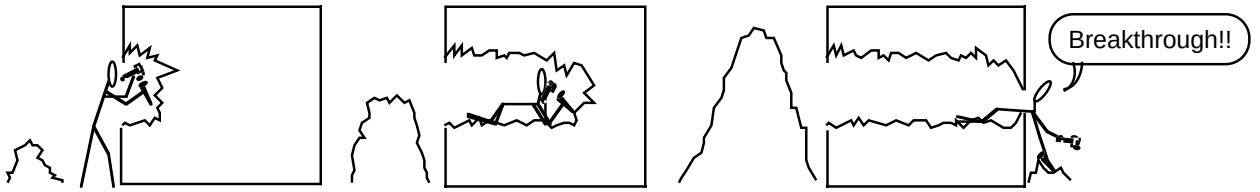

Figure 4

Even though the person may have been boring through for a very long time, removing lots of little incremental chips from the wall, the moment of breakthrough is when the person finally begins to emerge through the wall. The same pattern holds in technology development or research and development. The breakthrough is usually the point where the results of extended effort (often by many people and groups) become apparent.

In his 1989 book *Photography Until Now*,[5] John Szarkowski describes the long and complicated prehistory of photography. The invention of photography is sometimes simplistically credited to Daguerre in about 1840 but, as Szarkowski shows, was really the result of the efforts of many people before and after Daguerre. As Szarkowski says:

> Inventions—the name by which we call devices that seem fundamentally new—are almost always born out of a process that is more like farming than magic. From a complex ecology of ideas and circumstances that includes the condition of the intellectual soil, the political climate, the state of technical competence, and the sophistication of the seed, the suggestion of new possibilities arises.
>
> Radical disruptions have long prior histories. After many incremental successes and nominal failures a new idea (which is generally not so new an idea) gains a measure of success that lifts it over the threshold into visibility, at which point it is given a name and begins its official history.
>
> In 1929 Abbott Payson Usher pointed out that it was futile to try to identify the inventor of mechanical printing, or the steam engine, or the airplane, since cultural achievement is a social accomplishment based on the accumulation of many small acts of insight by individuals.[6] Mr. Usher surely did not mean to suggest that each of these acts is of equal importance, but rather that the most imaginative and thrilling of them stood on the shoulders of a thousand earlier contributions.

I could give many similar examples of how contemporary companies, including my own, are often credited and take credit for a breakthrough that in fact had a long prior history of incremental developments.

It is possible for breakthroughs to happen in a single act of brilliant insight with no incremental buildup. However, such occurrences are so rare and undependable as to be nearly irrelevant to our business needs.

[5] The Museum of Modern Art, 1989.
[6] Abbott Payson Usher, A History of Mechanical Inventions, Harvard University Press, 1929, pp. 65-68.

Patterns leading to breakthrough

a. the long slow climb,

b. the long, apparently fruitless quest that finally pays off,

c. the effort that requires breaking down old inefficient practices before new techniques can be implemented and pay off,

d. the alternation of small improvements and plateaus of no improvement, as when learning many physical skills, such as playing tennis or playing a musical instrument, or

e. a combination of the above

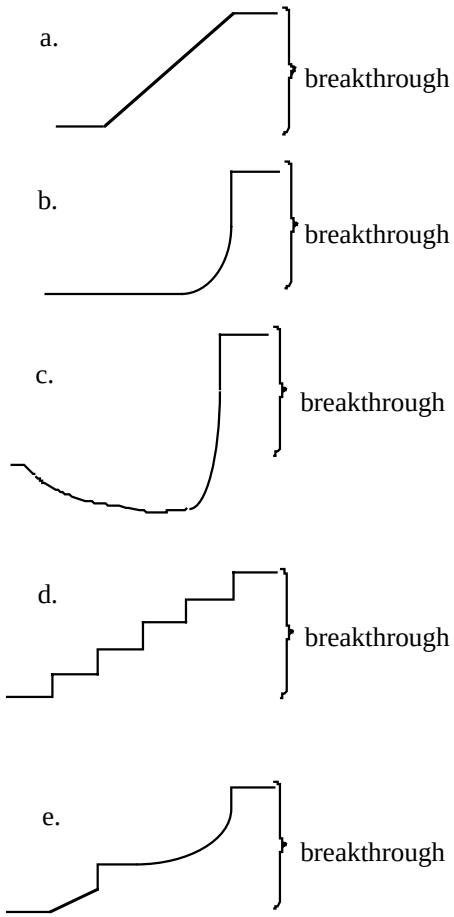

Figure 5

More likely patterns leading to breakthrough are shown in figure 5.

In research and development, incremental improvement is most often the means of breakthrough, and breakthrough is the culmination of incremental improvement. Incremental improvement is far from being incompatible with breakthrough in research and development; scientists and engineers are unusual in their ability to keep slogging month after month and year after year until the "breakthrough" finally results. Many other kinds of people would have given up long before.

The Relationship between Breakthrough and Incremental Improvement Varies with the Maturity of the Industry

The relationship between breakthrough and incremental improvement may vary with the maturity of a technology or industry. The curves in figure 6 (next page) illustrate how this works.[7]

The curve starting at the top left of the figure shows a decline in the importance of breakthrough or size of discontinuities as industries or technologies mature. For instance, in the semiconductor industry, quantum mechanics, the band theory of semiconductors, and the silicon transistor represented giant intellectual changes. The integrated circuit and later the DRAM, EPROM, and microprocessor were great changes, but not so fundamental as quantum mechanics, the band theory, or the silicon transistor. In the 1980s and 1990s there have been many very significant improvements, but in many ways they are variations on what has gone before, such as denser packaging, RISC processors, and the multibus.

The curve starting at the bottom left of figure 6 shows how the importance of incremental improvement can increase as the size of breakthroughs decreases. There are two reasons for this increase in importance of incremental improvement. First, as technology becomes more broadly applied, improvements of the production process become a necessity and an important source of competitive advantage.

[7] The ideas in this final section were pointed out to me by Dr. Dennis Buss of Analog Devices, Inc.

The relationship between the maturity of an industry and the importance of breakthrough vs. incremental improvement

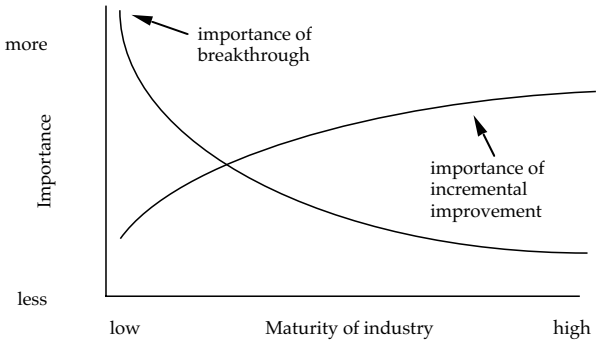

Figure 6

Second, as the technology becomes more mature, each improvement tends to be harder and more complex to achieve and thus takes more process. For instance, it probably took only a few people to develop the first DRAM. Now development of a 16-megabit DRAM takes hundreds of people to do all the work and deal with all the little problems and complexities. No one person can understand it all. In this situation lots of process and lots of improvement of the process is necessary for success.

Other industries, such as the automobile industry, may be even more mature than the semiconductor industry, while genetic engineering, by contrast, may be operating at a point where breakthroughs are relatively more important and incremental improvements are relatively less of a competitive advantage than in the maturer industries.

It is important for each of us to consider the relative importance of breakthrough and incremental improvements in our own industries to determine how much we must focus on incremental improvement to remain competitive. ■

Acknowledgments

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