'Dominant science does not mean dominant product'

Understanding the manufacturing-development process is the key to industrial leadership according to Ralph E. Gomory, IBM's senior vice president for science and technology, in his 1987 Scientist of the Year lecture.

Ralph E. Gomory

I HAVE BEEN FORTUNATE to live through a period of enormous excitement in science and technology, a period that has demonstrated in unforgettable ways that science, in addition to being a great intellectual pursuit, also has enormous practical power.

This practical power has been made evident to everyone. First, in the stunning sudden appearance of the first atomic bomb. The atom bomb was a practical end result of the gradual buildup of knowledge about the atomic structure and the nucleus over the previous 40 years. This work generated a practical power which, in its first appearance, put an end to World War II and, in its subsequent refinements, has given us the power to perhaps end our entire world.

Second, in the appearance and rapid evolution of the transistor—itself the end result of the steady buildup of scientific knowledge in the form of quantum mechanics and solid-state physics over the decades since the 1920s. A development which today, in the form of silicon chips, is rapidly transforming the world around us (and leading toward the mechanization of thought).

And even more recently in the spectacular scientific success of molecular biology and its practical ramification—biotechnology—which seems to be well on the way to affecting living beings themselves in a profound and transforming fashion. Thus, in a relatively short time, science has demonstrated its power to destroy the world, to create machines that can execute a hundred million operations in a single second, and that probe the secrets of the construction of life.

These stunning examples of the power of science have led to a national consensus that has supported science, and this country has been, since World War II, the dominant scientific power of the world. But to the surprise of many, dominant science has not turned out to mean dominance in products. Automobiles, steel and, more recently, semiconductor memories have shown that dominant science does not mean dominant industry even in the most high technology areas.

But we should realize that it never did.

Long before, as well as after, World War II, the U.S. was the dominant industrial power of the world.

Before World War II, that world had not been devastated and the other industrial powers had not been weakened.

In the 1920s, the U.S. produced more than two times the iron, steel, and electricity of France, Germany, and Britain combined, and also more than twice as much per capita. It was on this massive and efficient industrial base that were built the overwhelming air and sea armadas of World War II.

All of this was done on a negligible U.S. science base. The capital of science in that period was Europe. But the capital of industry was the U.S. One can say with some truth that we were the Japan of that period.

If dominant science does not mean dominant product, what then is their relationship? Let us look more closely at this question.

Two types of development

It is first necessary to realize that the dominance of science and scientists in the atomic bomb and biotechnology provides an example, a type, or a paradigm for the introduction of radically new technology. However, it is not a paradigm for the more ordinary processes of product development.

The radical process we have just been talking about we will call the ladder process. It is the reduction to practice of a new idea. The new idea being dominant, the product forms itself around the new idea or new technology. Those who understand that idea or technology, often scientists, play the dominant role.

However, there is another process which I will call, in contrast to the ladder, the cyclic development process or, sometimes, the process of repeated incremental improvement.

In this type of process improvement, an existing (not new) product gets better and develops new features year after year. Though this may sound dull, the cumulative effect of these incremental changes can be profound.

It is this process of incremental improvement that, after the initial great ladder-style transistor event, each year has given us better computer memories. In the past 20 years of incremental improvement, we have gone from one bit on a chip to one million. Incremental improvement is also the process that each year gives us better-resolution screens and quieter and better-quality printers.

This process of gradual improvement is enormously important. Most products sold today were here in slightly inferior form last year, and most competition is between variants of the same product. Competition is usually my auto against your auto, not my auto against your helicopter.

And in the area where the U.S. has not been competitive, it has lost, insofar as technical factors are concerned, usually not to radical new technology, but to better refinements, better manufacturing technology, better quality in an existing product, etc.

Certainly there are significant economic factors as well (wages, exchange rates, and cost of capital). But tonight we are focusing on technology. So let us look for a moment at the incremental product improvement cycle. Certainly it varies from industry to industry and my description will not apply to some, but also there is much that is common.

One important point to realize is that the world of incremental product development is, by definition, a world built around the existing product. Not as in the ladder process around a new idea. The people who know that existing product best, and who decide what happens, are the ones already there. What they can do to improve the product is strongly affected by what it already is.

Second, there is a cyclic nature to the process. In the world of computers, printers, displays, etc., while the current version of the product is in manufacturing, a development team is working on the next product generation.

For example, manufacturing could be making 256-k memory chips, while development is working on the process, the other refinements, and the design for a 1-M chip. When that is ready, the 1-M chip is introduced into manufacturing which gradually builds up production and phases out the 256-k chip. Then the development process starts again on a 4-M chip. A similar-style cycle of production—improved product, new production—applies to printers, etc., and in many of the areas you are familiar with.

One consequence of this cyclic process is that the speed of the development-manufacturing cycle is vital. If one company has a three-year cycle and one has a two, the one with the two-year cycle will have its process and design into production and in the market one year before the other. The one with the shorter cycle will appear to have newer products with newer technologies, etc. In fact, both companies will be working from the same storehouse of technology. It is the speed of the M&D cycle that appears as technical innovation or leadership. It only takes a few turns of that cycle to build a commanding product lead.

A key factor in the speed of the cycle, as well as in its quality and cost, is the close tie between development and manufacturing. Design for a manufacturable product results in rapid introduction and buildup in manufacturing. Close ties between manufacturing and development translate into early knowledge of technical problems, into speed of introduction, and into quality. And the lack of these ties does the opposite.

Another common feature of this M&D cycle is its relative imperviousness to ideas coming from outside itself.

If you want to get new ideas into the cycle from the outside, there is a right moment. You need to propose them at the beginning of the cycle—halfway through it is too late. If you propose a better printer head one year into a two-year cycle, the proposal is useless. Furthermore, the ideas—say the new head, for example—will need to be pretty well fleshed out and tested so the development team can expect to finish in time even when the new head concept is available at the start of the cycle.

Another complication is the fact that the product is often too complicated or uses processes that are too complex to be understood either completely or scientifically. Examples of this are electroplating baths whose composition or effects of components is not known, complex reactions with ions in a plasma on surfaces, or even the vibrations and other factors affecting the flight of a head over a disk.

Often in development and manufacturing, you don't know exactly how something works, but it worked last time. In this situation, small evolutionary changes are more acceptable than large radical ones.

Dominance of the existing product—consequences

All of these are manifestations of the fact that the existing product is there and is being refined by new ideas. The product, its complexities, what the development and manufacturing teams know or don't know—these are the factors that often dominate, and these factors are often only understood by the development teams themselves.

It is not like the atom bomb, transistor, ladder paradigm where a whole new thing is built around a new idea.

All of these factors weigh heavily against ideas from the outside and even more against ideas at a university level of development.

If new ideas are difficult to get into the cycle from the outside, then those who are involved, and understand the present state of affairs in detail, must themselves be the bearers of new ideas.

This means that the product engineers themselves must be up on the relevant science and technology. They are often the only route in for new ideas. And if they are not up on what is happening technically in other companies, or in universities, a high level of technology in the infrastructure will go to waste or, more likely, be seized by a competitor.

The travel-to-meetings budget, reading the technical literature, being a part of the engineering community—all of this is not a frill, nor is it an indulgence given to the professional ambitions of the engineer. It is a necessity if we are to compete with those who make those efforts, and are then able to incorporate change into their own complex product worlds.

Our effective foreign competition to date has been characterized by tight ties between manufacturing and development, an emphasis on quality, rapid introduction of incremental improvements known to all, into a rapid development cycle of a pre-existing product. And a tremendous effort by those actually in the product cycle, to be educated on the relevant technologies and on what is going on in the world and in the competition's product.

These are the things that we too must excel at.

Other factors

Let us look briefly at factors outside this hard-to-affect M&D cycle. One is in-house research.

An in-house research organization in industry, if it is to succeed, must be closely tied to the manufacturing and development cycle. With these close ties, it can understand the progress of the cycle, can present new steps at the appropriate time, and have these fleshed out enough to have them be acceptable. Familiarity at a personal level also helps to build acceptability.

All of this is much harder to do from a university base, and even harder from government labs as they now are constituted.

Cooperative intercompany research (not manufacturing and development) could help. Especially if these are temporary groups made up of people from the home company who return with new knowledge and reenter the cycle.

What about "reduction to practice" government prototypes, reforming the educational system, strengthening the national science base, etc.?

These things are all good and help build a strong foundation, a strong infrastructure. But they are unlikely to affect the M&D cycle itself. Their effect will be less direct and more long term.

Ladies and gentlemen, we need to recognize the difference between the more-spectacular ladder style of innovation and the more-common cycles of product development. And we need to excel at both.

Because cyclic style development is so hard to affect from the outside, there is perhaps a limit to how much we in industry, as practitioners, can be helped from the outside.

In the past, we have been very successful at translating the tremendous power of science into new technologies, using the ladder process. Now we need to think about ways of bringing that power to bear upon the relatively hard-to-affect product development cycle. This certainly is a significant part of the problem of industrial competitiveness.

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