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Turning Ideas into Products

It is the speed of the development and manufacturing cycle that appears as technical innovation or leadership.

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Events of the past 40 years have demonstrated in unforgettable ways that science, in addition to being a stimulating intellectual pursuit, has enormous practical power. This power has been made evident to everyone.

It was evident first in the stunningly sudden appearance of the atomic bomb — the practical result of the gradual buildup of knowledge about the atomic structure and the nucleus over the previous 40 years.

A second example of the practical power of science was the appearance and rapid evolution of the transistor — again, the result of a steady buildup of scientific knowledge (this time, about quantum mechanics and solid-state physics) since the 1920s. Today, this development, in the form of silicon chips, is rapidly transforming the world around us.

A more recent example is the spectacular scientific success of molecular biology and its practical ramification — biotechnology — which seems well on the way to affecting living beings themselves in a profound and transforming fashion.

Scientific versus Product Dominance

Since World War II, the United States has been the dominant scientific power of the world. But, to the surprise of many, automobiles, steel, and semiconductor memories have shown us that dominant science does not automatically 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 — before the world was devastated and the other industrial nations weakened — the United States was the dominant industrial power of the world. In the 1920s, for example, the United States produced more than twice as much iron, steel, and electricity as France, Germany, and Britain combined (and also more than twice as much per capita). It was on this kind of 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 the early 1900s was Europe. One could say with some truth that we were the "Japan" of that period.

To understand why dominance in science does not necessarily mean dominance in products — and how the United States today can continue to excel in generating new scientific ideas, but not so much in generating competitive products — we need to think more concretely about the *connection* between science and products. We need to realize that the dominance of science and scientists in creating the atomic bomb, the transistor, and biotechnology provides an example or paradigm for the introduction of radically new technology, but not a paradigm for the more ordinary process of product improvement.

Two Different Development Processes

The radical process I have been talking about so far (that produces, for example, a transistor), I call the "ladder" process. It is the step-by-step reduction to practice of a new idea. That new idea being dominant, the product forms itself around the new idea or new technology. And those who understand this idea or technology (often scientists) play the dominant role. However, there is another (indeed, much more common) process of innovation, which I will call, in contrast to the ladder, the "cyclic development" process, or the process of repeated incremental improvement. In this type of improvement process, an existing (not new) product gets better and develops new features year after year. Though that may sound dull, the cumulative effect of these incremental changes can be profound.

It is this process of incremental improvement that — following the initial great ladder-style invention of the transistor — has given us every year larger and better computer memories. In the past 20 years of incremental improvement, we have come from one bit on a chip to 1 million bits. Incremental improvement is also the process that each year gives us higher-resolution display screens, quieter and better quality printers, and so on. 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. In areas where the United States 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, or better quality in an existing product.

Characteristics of Cyclic Development

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 next, are the ones already involved with it. And what they can do to improve the product is strongly affected by what it already is.

A second point to be aware of is the cyclic nature of the process. In the world of computers, printers, and displays, while the current version of a product is in manufacturing, a development team is working on the next product generation. For example, manufacturing could be making 256-kilobit (K) memory chips, while development is working on the process, other refinements, and the design for a 1-megabit chip. When they are ready, the megabit chip is introduced into manufacturing, which gradually builds up production and phases out the 256K chip. Then the development process starts over again on a 4-megabit chip. A similar cycle of improved product and new production applies to most products in my industry, and to the products of many other industries as well.

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Speed Is Crucial

One consequence of this cyclic process is that the speed of the development and manufacturing cycle is crucial. If one company has a three-year cycle and one has a two-year cycle, the company with the two-year cycle will have its process and design into production and in the marketplace one year before the other. The company with the shorter cycle will appear to have newer products with newer technologies. But, in fact, both companies will be working from the same storehouse of technology. It is the speed of the development and manufacturing cycle that appears as technical innovation or leadership. And it takes only 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 relationship between development and manufacturing. Design for manufacturability results in a rapid start-up of production. Likewise, 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 development and manufacturing cycle is its relative imperviousness to ideas coming from *outside itself.*

Getting Ideas into the Cycle

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 is too late. If you propose a better print-head one year into a two-year printer development and manufacturing cycle, the proposal is useless. Furthermore, even when the new concept *is* available at the start of the cycle, it will need to be pretty well fleshed out and tested so that the development team can expect to finish their work on the idea in time. Another complication is the fact that the product is often too complicated, or uses processes that are too complex, to be understood completely. Examples are electroplating baths of unknown composition or effects, reactions of ions in a plasma with surfaces, or even the vibrations and other factors affecting the flight of a read-write head over a magnetic disk.

Often in development and manufacturing, you do not know exactly how something works, but it worked last time. In this situation, small evolutionary changes are clearly more acceptable than large radical changes. All these things 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 do not know . . . these are the factors that often dominate. And these factors often are understood only by the development teams themselves. This is nothing like the transistor ladder paradigm, where a whole new device is built around a new idea. All of these facts weigh heavily against ideas from the outside, and even more against ideas at a university level of development.

Keeping Well Informed

If new ideas are difficult to get into the cycle from the outside, then those people who are part of the cycle and who 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 well informed on the relevant science and technology, for they are often the only route in for new ideas. And if they are not up to date about 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, will be seized on by a competitor. The travel-to-meetings budget, reading the technical literature, being a part of the overall engineering community — all of this is not a frill, nor is it an indulgence to the professional ambitions of the engineer. It is a *necessity* if we are to compete with those who do make these efforts, and thus are better able to incorporate change into their own complex product worlds.

Factors in Effective Competition

Our most effective foreign competition to date has been characterized by

- Tight ties between manufacturing and development;
- An emphasis on quality;
- The rapid introduction of incremental improvements often known to all in the development cycle of a preexisting product; and
- A tremendous effort, by those actually in the product cycle, to be educated on the relevant technologies, on the competition's products, and on what is going on in the world.

These are the things at which the United States, too, must excel. Much of what needs to be done in U.S. industry emerges from a better understanding of the cyclic development process: closer ties to manufacturing, design for manufacturability, a rapid design cycle, and ensuring the technical up-to-dateness of the engineers themselves. Another thing that emerges from this picture is the self-contained nature of the product development world, and the factors that make this world relatively hard to affect from outside itself.

What about Outside Factors?

Nevertheless, let us look briefly at several elements outside the development and manufacturing cycle. The first is the important area of the company's own in-house research organization.

An organization for research (as opposed to development) in industry must be closely tied to the product improvement cycle if it is to succeed. Only through close ties to development and manufacturing can it understand the progress of the cycle, present new steps at the appropriate time, and have them fleshed out enough to be acceptable. Familiarity at a personal level also helps to build this acceptability. All of this is much harder to do from a university base and even harder from government laboratories as they are now constituted.

Second, cooperative intercompany research (not development and manufacturing) can sometimes help — especially if it is performed by temporary groups made up of people who afterward return to their home companies with new knowledge, and there reenter the cycle. Further considerations include reform of the educational system, strengthening the national science base, and so on. These things are all good and help build a strong foundation — a strong infrastructure. But they are unlikely to affect the development and manufacturing cycle itself in the short run. Their effect will be less direct and more long term. Indeed, it may be that governmental policies in this area need to be formulated with the properties of the development and manufacturing cycle in mind.

The United States has been very successful at the science and scientist-dominated "ladder" type of innovation, where a wholly new idea moves from research into a wholly new product. But there is no escaping the fact that we must learn to succeed also in the rapid, cyclical, engineer-dominated process of incremental product improvement. Neither process is a substitute for the other. We need both.