Why We Need Basic Research

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Human Society is at a perilous point. Science and technology have enabled us to prosper and multiply as a species. Our population is expected to cross the nine billion mark in the middle of this century and industrialization is spreading across the world as developing nations strive to improve their standard of living. Human activities are transforming the surface of the earth, but in the process we are damaging the planet's ecosystems on which we vitally depend. One of the greatest challenges we face is creating a sustainable world. At present humankind is rapidly depleting its environmental bank. Human activities are threatening the global biological and geophysical systems on which all life depends for air, food, energy and an acceptable environment. What must we do to address the critical challenges that we face at the beginning of the 21st century?

We must develop a better understanding of ecological and environmental issues, provide guidance to policy makers in these areas, and develop new technologies that abate or reduce our environmental threats. Of special importance is decreasing human-produced greenhouse gases that are entering the atmosphere and threatening to produce catastrophic global warming. If atmospheric greenhouse gas levels are allowed to go beyond a critical level, which experts say is possible by mid-century on the basis of current trends, the impacts on the planet and human society will be severe. It is likely that such a catastrophic development would result in reduced crop yields in many parts of the world; reduced supplies of fresh water; more severe storms, droughts, forest fires of increasing intensity; an increase of infectious diseases; lethal heat waves; large scale species extinction and coastal flooding that could create tens of millions of refugees. Humankind must do everything that it can to avoid these dire possibilities.

We have to develop alternative sources of clean energy that do not increase the concentration of greenhouse gases in the atmosphere. This is an especially challenging issue, because improving the standard of living of developing nations will require significant increases in their use of energy.

We have to improve the general health of the populations in all parts of the world, and in particular control the spread of infectious diseases, both old and new. A 2005 World Health Organization report suggested that global warming may already cause 150,000 deaths annually, primarily by spreading illnesses that are prevalent in hot regions of the world.

We have to provide ample clean drinking water in all parts of the world. At the present time, depletable ground water supplies are being over exploited and contaminated. About one billion people lack access to clean drinking water and roughly 40 % of the world's population regularly experience serious water shortages.

We have to eradicate hunger. It will be a formidable challenge to provide sufficient food for the rapidly growing population of the world.

To solve many of our global problems, we have to improve current technology and develop innovative new technologies that have the capability of addressing these issues. This will require greater investment in basic and applied research and in education. Not only will this help create a sustainable world, this will also have a huge impact on the economies of nations, because new technologies will give birth to new products and new industries. But it is important that we do not fall into the trap of thinking that only applied research is needed.

Why is basic research in science so important? Why not just invent radically new technologies? This approach will not work because, as we have seen from history, new, truly revolutionary technologies have been invariably based on new scientific knowledge. Even scientific research that appeared to have no possible applications has led to applications that have changed the way we live. The thesis that I want to propose today is that the major innovations of the future - -- those that will solve our greatest problems and shape the society of the future -- will require a foundation of strong basic research. Innovation <u>is</u> the key to solving the planet's problems, but basic research is the key to future innovation.

While applied research and invention play important roles in innovation, they do not in general produce the major conceptual breakthroughs that are necessary for creating radically new technologies. The limitation of focused research, or problem oriented research, becomes apparent in the following observation. If you know what you are looking for, you are limited by what you know. And as inventive as Thomas Edison was, he could not have invented the transistor, one of the most important developments of the 20th century – a development that has enabled modern technology to flower.

To demonstrate this point, it is useful to trace the history of the development of the transistor, which perhaps was the most important invention of the 20th century – an invention that is imbedded in almost all of our technology and has changed the way we live.

It started in the latter part of the 19th century, when physicists started studying the atomic spectra of various elements. The spectra that were observed consisted of discrete lines.

There was great controversy about the structure of the atom, but in 1911 Rutherford discovered the atomic nucleus in alpha particle scattering experiments and confirmed the "solar system model" of the atom that had been proposed by the Japanese physicist, Hantaro Nagaoka in1904. However there were theoretical problems with the stability of the atom in this model – it predicted that the atom would decay in about a nanosecond.

But in 1913 Bohr, using the quantum ideas of Planck and Einstein, developed a semi-classical model of the atom based on a quantization of the electron orbit. It accounted for the discrete spectra of hydrogen and established a new paradigm for the stability of the atom. It was, however, only an approximate theory. Then between 1925 and 1926 Heisenberg and Schrodinger developed quantum mechanics. This was a complete non-relativistic theory of the hydrogen atom that explained the measurements of the spectral lines of hydrogen.

In 1928 Bloch applied the full machinery of quantum mechanics to the problem of electrical conduction in solids, spearheading the development of the modern theory of solids between 1928 and 1933. Then in 1929 Schottky and others pointed to the existence of electron "holes" in the valence-band structure of semiconductors, uncovering the mechanism of the behavior of semiconductors.

These advances culminated in the invention of the transistor in 1947 when Bardeen and Brattain took out a patent for a transistor; and Schockley applied for a patent for the transistor effect and a transistor amplifier. And by1955, transistors began replacing tubes. Then in 1959, the integrated circuit was invented by Noyce and Kilby; and the microchip was the beginning of a new technological revolution.

What this example demonstrates is how curiosity driven basic research established the foundations of the technological revolution created by the invention of the transistor. It is ironic that quantum mechanics, one of most abstruse conceptual frameworks in physics - one that was developed to explain the structure of the atom - lies at the foundation of some of our most important technological developments. It contributed to the development of technologies that gave us world wide communication, computers with their applications to all phases of modern life, lasers with many diverse uses, consumer electronics, atomic clocks, and superconductors - just to mention a few. In modern industrial nations, quantum mechanics probably lies at the basis of a sizable fraction of the gross national product.

Although I have emphasized basic research, the above examples demonstrate that all types of research are required. Applied research, and product development have also played crucial roles in the development of the transistor. New technologies clearly cannot be created without a synthesis of all three. And often the boundaries between these types of research get blurred. Applied research sometimes leads to important basic knowledge. And very often, applied research is an essential component of basic research because existing instrumentation is not adequate for pursuing a particular area of scientific research and new types of technology have to be developed. These new technologies often lead to spin-offs, which have broader applications in society.

For example, accelerators were invented to study the interactions of sub-atomic particles, and now various types of accelerators are used for such diverse applications as cancer therapy and the fabrication of semiconductors and microchips. Synchrotron light sources are being used to design new drugs, study the structure of viruses and study new types of materials. Other examples are the World wide web, the Global Positioning System, nuclear medicine, and diagnostic tools such as magnetic resonance imaging, positron emission tomography, and computerized axial tomography.

Economists have studied the impact of research on the Gross National Product or on other measures of wealth or well being. This can be seen as a measure of the economic impact of the innovations derived from such research. Economists have estimated that 1/2 to 2/3 of the economic growth of developed nations is science based while there is uncertainty in these numbers, there seems to be no disagreement that the impact is huge and the past investment in research has paid for itself many times over.

But who will support basic research in the future? Industry, which supported a significant amount in the past, generally does not do so any longer. Fierce global competition has put enormous economic pressures on industrial corporations. Private industry will make R&D investments that are expected to pay off within 5 to 7 years, but it won't make the 20 to 30 year investments that are necessary to create entirely new industries. Long- term investments in Research & Development have been cut as firms have merged and down-sized. Monopolistic companies that used to do long-term R&D, such as AT&T and IBM, have seen their industries become highly competitive. To compete they have largely withdrawn from supporting basic research.

I remember discussing this matter with a friend who is a prominent scientist in a corporation that did significant basic research in the past. I asked him where his firm got its ideas for future developments. He said, "We don't do research - we search." But this approach requires someone to do the research. Who will do it? It is clear that basic research must rely primarily on government support, either national or local.

This is also being seen in another trend. Patents are a strong indicator of innovation. A study prepared in 1997 found strong evidence that publicly financed scientific research plays a large role in the breakthroughs of industrial innovation in the United States. The study, prepared for the National Science Foundation by a private research group, found that 73% of the main science papers cited by American industrial patents in two prior years were based on domestic and foreign research financed by government or nonprofit agencies. Such publicly financed science, the study concluded, has turned into a "fundamental pillar" of industrial advance. This shows the close connection between national science budgets and the economy. It also points to the importance of establishing good bridges between universities, government, and industrial laboratories.

You might wonder why I am stressing the importance of basic research in this talk when applied research and product development also play important roles in innovation. I am making this point because of all the types of research, basic research is the most vulnerable.

Basic research is an activity that seeks scientific knowledge for its own sake without thought of practical ends. It is inherently a risky enterprise. Neither its outcome nor its applications can be predicted in advance.

And as was shown in my example of the development of the transistor there are often long delays in the applications that arise from basic research. Because of these factors, the importance of basic research is often not well understood by the public and by political leaders. When some new important scientific result is announced and the public asks how it will benefit society, the scientists involved often don't have a clue as to how to answer this question. In general, they cannot make any promises about its future applications.

If we can't make any promises about the success or applications of basic research, how do we communicate its importance and relevance to the public and political leaders? They and political leaders want to hear arguments about applications, economic growth, and competitiveness.

We can make such arguments; but if they want examples, we can only talk about the past, because we are not able to make specific promises about the future. But we can use history as a guide. We can tell them that throughout history, advances in scientific knowledge have resulted in revolutions in technology that have improved the standard of living and changed our way of life. Although, direct benefits to society from the applications of basic research generally require a number of decades, they do come. After all, electricity and magnetism were laboratory curiosities in the early 1800's but did not become a factor in people's lives until more than a half of century later. But the applications of electricity and magnetism have had a dramatic impact on the way we live. The history of the transistor demonstrates the same long delay and huge pay-off to society.

I would like to summarize the key elements needed for sustaining major innovation in the future:

* There must be strong support for basic, applied, and engineering research from government and industry -- basic research requires special attention.
* We need an educational system that encourages and nurtures creativity.

There should be a great emphasis on inquiry & intellectual independence.

* Centers of Research (Universities, Industry, Government) should strongly support the research of young scientists and engineers and be willing to take risks.

* We need to maintain strong Research Universities. They are the source of cutting-edge research and the future scientific work force.

* We must maintain good bridges between Universities, Government and Industrial Laboratories.

* We must keep the public informed about science and technology in order to maintain its support and minimize technological backlash.

In conclusion, to address and reduce the serious problems that afflict the world we need the efforts of science, applied science and engineering. To achieve our goals, we need to expand our base of knowledge and need to educate our young people so they can utilize and further expand this knowledge. It is my conviction that ample investment in science and technology is an absolute necessity to develop the innovations we will need for the future. Innovation is the key to the future and research is the key to future innovation. Only by making such investments can nations protect the environment, ensure future improvements in their standard of living and stimulate economic growth.