Change In the Meaning of Science

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For many students who have an interest in science or engineering the words "science" or "exact science" have a very special meaning. They create a vision of an imperishable structure of facts and knowledge. They suggest mankind's accumulated wisdom and truth about the regular and repetitive, machine-like operations of nature. They also provide assurance that the universe is now understood and that only additional data remains to be added to our present knowledge. Moreover, they promote the confidence that the answers to all, or at least most, human questions can be found in science, and that in science lies the hope for the future.

In fact this concept of science is not only held by young people, but is probably the most common view of science held by people in the America of the 1980's. Although there are many expressions of disappointment with the extent and pervasive influence of technology and with the rapid change it has brought to people's lives, confidence that science has explained the universe, that relationships in nature have been properly expressed in scientific terms, and that the methods of science can be applied successfully in all areas of human activity continues.

This concept of science is the product of the great achievements in science since the seventeenth century and of the attitudes which have accompanied and encouraged the scientific development in the period of the seventeenth to nineteenth centuries.

In the seventeenth century there were several competing, commonly held views of science which had continued from the earliest periods of Western culture and had been developed and modified through the middle ages. According to one of them the universe was, to a certain extent, an organic entity which should be studied holistically as one would study the plant or animal kingdoms. To another, nature was a mystery which was to be treated and understood in the terms and by the methods of alchemy, astrology, and magic. Still another presented the universe as being similar to a complex machine.

This mechanistic philosophy of the universe emerged into modern times particularly through the work of Galileo and a few contemporaries at the end of the 16th century. In 1644 this view was also presented by Descartes, who said that he did not "recognize any difference between the machines that artisans make and the different bodies that nature also creates."[1]

The mechanistic concept views all nature as a vast system of motions occurring in an absolutely regular way, and it promotes the confidence that these motions can be discovered and understood by careful examination, just as one can figure out how a machine works by careful examination and observation. It is based on the faith expressed by Galileo that "the conclusions of science are true and necessary, and the judgement of man has nothing to do with them."[2] By the end of the seventeenth century this mechanistic world view was the dominant philosophy of nature among men of science in Western Europe, and at least by the middle of the nineteenth century had become the popular world view of Western culture.

Our modern technological world is a proof that this has been a very productive concept, and it is generally accepted that science will continue to be productive and to provide answers to the riddles of the universe. This picture of science is apparently acquired by young people as they are introduced to the scientific disciplines. Their contacts with the history of science lead them to believe that the men who have contributed to this mechanistic view are the benefactors of mankind who have contributed to the correct understanding of nature, which they are confident that we now have. People who have held other views about nature are unknown or are considered unscientific.

It is somewhat strange that science has this meaning generally, and that the mechanistic concept retains this popular confidence in the correctness of its picture of nature. For well over fifty years now the meaning of "science" has been much changed for many of the world's leading scientists.

If we consider the period since Galileo to have been the modern era of science, then in the twentieth century science has moved into a post-modern era. The beginning of this era is generally considered to be marked by the introduction of Planck's quantum mechanics in 1900. Developments since then have forced scientists to recognize that science is not based on principles of universal validity, and that the judgements of man do have much to do with the conclusions of science. They have been compelled to recognize that the questions that men of science ask are as important as, and even anticipate, the answers they provide. However the significance of the developments in twentieth-century science has not been widely understood, and the general public seems to hold the world-outlook of the Galilean revolution rather than that of the twentieth-century revolution in science.

Perhaps its world-view has never been broadly accepted, because the science of this century presents a universe which cannot be visualized. But whatever the reasons are that their ideas haven't gained a wide acceptance, leading twentieth century scientists have had much to say. Planck, Jeans, Eddington, Heisenberg, and others have discussed their understanding of the implications of modern science in many lectures, essays, and books. Their ideas provide a modern concept of science with which science and engineering students of the present time ought to be familiar.

Contrary to the popular view, these scientists do not believe that the real world can be fully known; they believe that because of human limitations, only approximate knowledge of nature is possible. They believe also that the approximate solution of one problem in nature only reveals the mystery of another, and they have come to realize that when man formulates the laws of nature, even though he does not prescribe those laws, he always adds something of his own. Moreover, they realize that their observations and measurements may disturb or affect the object they are observing and prevent a true evaluation of natural events. Thus, even though it is the business of science to try continually to refine its work, they never expect it to provide a description of nature which is in exact agreement with reality.

Modern scientists abstract a world-picture from the data of science, but it is not the world of our perceptions. for example Einstein's warped, space-time continuum is not something that can readily be perceived. The scientists see themselves as taking a disordered, subjective collection of facts and replacing it with a constant, objective, abstract world, a replacement of irregularity and randomness by law. Moreover, they do not consider this abstraction to be constant; it is subject to change at any time, and it never acquires a final character. They develop and elaborate this abstract world continuously, always striving for a better, more complete concept. In striving thus for a better conception of nature, they seek absolutes. However, they realize that what they assume to be absolutes today may not remain so for all time. Their absolutes are ideal goals which will never be attained, but will always remain somewhere ahead. They do not consider the pronouncements of science to be certain, but only as the most probable on present evidence. They expect the existing, abstracted world of science to be disrupted by new facts and new knowledge. The new facts and new knowledge, however, don't become important for them because they represent truth, but because they might establish interconnections which would permit or indicate broader generalizations, and because they might give direction to new investigations and to the development of new ideas again.

They see such new ideas growing out of research measurements which contradict, or at least fail to support older hypotheses. When this happens it indicates to them that a new structure is developing which will push aside or break down the older one. The new structure may retain what is useful in the old, but it will represent a significant change. In this process of change scientists consider progress to be made, because such fundamental structural change will uncover a series of new problems and will require a new program of experimental research to test the new scientific doctrines.

Such changes are not readily made. A consideration of the history of science suggests that the strong pressure of well-tested theory is necessary to cause change in the structure of science. Everyone knows for example, of Galileo's struggle to get his ideas accepted, and at the beginning of this century Max Planck's views were met with considerable resistance, as were Einstein's some years later. In fact, Planck, as a result of his own experience, gave some consideration to changes in scientific theory. He explained, for example, that the "main difficulty about the acceptance of the relativity theory was not merely a question of its merits, but rather the question of how far it would upset the Newtonian structure of theoretical dynamics."[3] He said that the more an older theory has been used, the more dependencies it has, and the harder it is to change. He thought that new scientific ideas don't triumph because opponents are convinced of their correctness, but rather because the opponents of these ideas eventually die off. The new ideas are then accepted, he believed, by a new generation, uncommitted to the older ones and familiar with the newer body of theory. Planck's ideas of scientific change certainly sound similar to ideas of social and political change and scarcely at all like Galileo's faith that the judgements of man have nothing to do with the conclusions of science.

Twentieth century science has not been seen then by its practitioners as complete truth arrived at or achieved, but rather as a process of changing ideas, a process of developing ever-better answers to the riddles of nature which are posed in each scientist's own time and place. The answers offered are somewhat uncertain, not only because of human limitations and interests, but also because of uncertainties of natural processes. While the mechanistic concept presents all nature as a chain of causes and effects occurring in an absolutely predictable way, modern developments have created a chasm between this view and the opinions of twentieth century scientists. According to the older concept one can determine from the natural events which occur today what happened in the past or predict what will occur in the future. For example, about one hundred years before Planck began his work, Immanuel Kant, who of course is best known for his philosophical works, wrote a number of treaties on scientific subjects. In one of these he posited a nebular hypothesis for the origin of the universe, reasoning from the conditions that were known in his day. In another paper he discussed the effect of tides on the rotation of the earth, concluding, on the basis of mathematical calculations, that they should have a braking effect on the earth's rotation which would become significant in the far distant future.

For twentieth-century scientists and philosophers such reasoning is not acceptable. They no longer hold the view that causality, determinism, and strict regularity exist in nature. They believe that these ideas are only illusions created by the operation of common, or the most-probable, occurrences, which, however, are not rules of an exact and universal validity. They tend to be indeterminists who do not believe that one occurrence necessarily determines a particular resultant occurence. Rather they hold an energy conception of nature, seeing energy as the basic stuff of nature, and aware of the interchangeability of mass and energy and the relationship between particles and waves. Nor do they find exact relationshipsin their investigations, but a scattering of results and measurements which causes them to see a statistical root in every law of physics. They see these laws as laws of probability, relating only to mean values of many observations, having only approximate validity for individual cases, and thus without any strict, physical regularity.

For people who accept such an idea of reality it would seem to be impossible to make predictions with any reliability or to develop a structure of science. To do so they are forced to make some assumptions about relationships in nature, and they, therefore, make some arbitrary suppositions. Among these suppositions is an idea of causality. However, twentieth century scientists do not see causally related occurrences as real events of nature, but only as the most probable, theoretical ones. For them the law of causality is neither "true" nor "false", but merely a heuristic principle, a guide to help them find there way in a bewildering maze of occurrences, a guide which suggests the direction in which scientific research must advance in order to achieve results.

The concept of causality in nature grew out of philosophical questions which were discussed by Greek philosophers in the fifth century B.C. and was based on prior assumptions about the nature of the universe. For a question of that time it provided an answer which fit well with answers which had been accepted for prior questions. Thus it can be seen to be a cultural development, and it provides an example of how the direction of science is related to and affected by the cultural milieu in which it grows. Modern scientists have an awareness of this and realize that measurements, facts, and data are applied to questions and hypotheses which are related not only to a special compartment of knowledge called science, but are determined by the total cultural environment of the scientific activities. As a result they see their answers to the riddles of nature as answers for their era only.

Many of the twentieth century scientists also believe there is more to the universe than its physical characteristics. Eddington, Whitehead, and Pauli were almost scientific mystics, convinced that in their scientific investigations they were delving into the mind of the universe. Planck saw science as working with data of experience, but always striving for the world of metaphysics. He thought that science and religion had the same objective--the recognition of an omnipresent intellect ruling the universe. He believed that both seek a rational order which cannot be directly known. However, he found them basically different in starting points and methods, with God the starting point of religion, but the ultimate, though unattainable, goal of science.

These are, of couse, only personal opinions. However, they are significant in that they show how much change there has been in the scientists' world view. These scientists have moved far from the idea of a machine-like world. They have become concerned again with questions raised in the early years of Western culture such as questions about meaning and purpose in nature. They have come to believe that the direction and conclusions of science to a great extent have been determined by the judgements and questions of man, and that in another cultural setting the same facts and data could support other conclusions. Again, we should note that this is almost the converse of Galileo's belief that the conclusions of science having nothing to do with the judgements of man. The use of the judgements of man to introduce regularity into the mass of perceived data is seen to be what science really is as an activity.

Apart from the fact that these are the views of some of the people who have created the science of today, these ideas have importance for our times. The mechanistic concept of nature has been satisfactory when it has been operating in terms of technology, but it has been ineffective in providing answers to questions concerning man. It has no answers for ethical, political or social questions. "Why sacrifice yourself for another person or cause?", "Why do one's duty?", "What is duty?", or even "What are important questions for science to ask?" are all questions which have no meaning in a mechanistic conception of the universe. In seeing science as a product of man's judgements and of its cultural setting, twentieth-century scientists see science not as beyond and above human control, but as only a part of the whole world of man. Their view has a humbling effect, perhaps, on men of science in showing the fallable and temporary character of their scientific conclusions. On the other hand it encourages all humanity by showing that man is not subject to an inevitable science, but that along with the arts, philosophy, technology and other human activities it is his own product.

A knowledge of the ideas of these twentieth-century scientists would lead students to appreciate the value and importance of other areas of their culture besides science. In encountering other areas they would broaden and enrich their lives and find help in establishing standards and goals for the scientific or technical vocations at which they aim.

This is of particular importance at the present time, because during the past century much importance was placed on the material conditions of society. It was, of course, correct to try to eliminate the material deficiencies of large parts of the world's population when technological developments made it possible to do so. But now that much has been accomplished, at least in the industrial countries, in health, nutrition, and other areas in which technology can supply the needs, much unhappiness still remains. It is apparent that individuals have other needs. Heisenberg, speaking in 1973, said that "if there is much unhappiness among today's student body, the reason is not material hardship, but the lack of trust that makes it difficult for the individual to give his life a meaning."[4] He believed this could be corrected by a more natural balance between spiritual and material conditions of life than have existed under the dominance of mechanistic science.

A balance between science and other cultural elements is more likely to be achieveable for people who are familiar with the science that Pauli, Eddington, Heisenberg, and Planck have encountered. They will be better able, with such familiarity, to gain an awareness of the tenuous character of scientific knowledge and to have a proper respect for opinions and objectives which are not based on science or presented in the language of science. Thus prepared, they will perhaps be ready to appreciate and address the problems that technology and science have created and to contribute to the direction of the total world of man.

NOTES

[1] R. Descartes, "Principia Philosophiae, IV" in Ouvres de Descartes, vol.8, p. 326.

[2] G. Galileo, Dialogue on the Great Would System in the Salisbury Translation ed. by G. de Santillana (Chicago: University of Chicago Press, 1953), p. 63.

[3] M. Planck, Where is Science Going?, (New York: W.W. Norton and Co., 1932), p. 44.

[4] W. Heisenberg, "Scientific and Religious Truth" in Across the Frontiers (New York: Harper and Row, 1974), p. 228.