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Date : 16/1/1990
Tape N# : 60A, 61A
Time code : 00:01:10:00
Subject : Technology

Antonello: What is the scientific revolution about?

00:01:10:00Þ Well as I see it, the scientific revolution was most important for bringing a new way of thinking to people, a new thinking cap. A new way of looking at problems, and believing that there were solutions to them. Many people believed that the essence of the scientific revolution was experiment, but it wasn't experiment alone because people had made experiments on and off before. What really mattered was what they did with the experiments. That they found new ways that they could make predictions based upon nature, coherent theories that were based on mathematics and above all, that were in the end congruent with the phenomenon that they were trying to explain.

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Antonello: From a social point of view what were the implications?

00:02:16:19Þ Well from the social point of view, for me, the big point of the scientific revolution was that it set up independent authority. Before the scientific revolution, people had based truth on great men, people who were holy men, holy women, people who were doctors, learned doctors of universities, of churches and so forth. The scientific revolution taught that the ultimate authority was nature, which anyone could explore or test for himself. The most beginning student who understood the methods of science could now make trial of nature for himself. And didn't have to obey authorities and statements made by authorities, if they didn't agree with what he could see himself.

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Antonello: How was this new knowlege diffused?

00:03:32:22 Well new knowledge was diffused in a number of ways. At the time of Galileo and of Kepler, through books and pamphlets, Galileo, as you probably are aware, was very much interested in the diffusion of knowledge, and so he wrote his big book on the Copernican System in the vernacular language, Italian. And many other scientists wrote in the new vernacular language, because they wanted to appeal to a new audience, they knew that the Latin speaking and Latin reading people in the university were fixed in their ways, and they wanted to appeal to new groups of members of society. At the end of scientific revolution, in the late 17th century, there were added the new feature of journals,

published by scientific societies. Collections of virtuosi, who believed in the new science and in the new method of knowledge. And then there grew up bands, there's no other word for it, bands of men and women devoted to spreading the new knowledge by lectures, by books written for popular consumption. Newtonianism, for example was spread by books in all languages, one was called, Newtonianismo per le Dame, Newtonianism for ladies. Implying in that time of culture that you didn't have to be someone who was able to go to a university and learn mathematics and learned languages in order to become aware of the new science. Finally, there were lectureships established so the artisans, sea captain, metal worker and others could learn the principles of this new science.

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Antonello: AT that time were there close links between science and technology?

00:05:47:00Þ The link between science and technology was announced as being close, but it really wasn't. By that I mean, that the scientist all declared ever since the time of Bacon and Descarte, that if you had real knowledge based on actual nature, that it could be applied to nature, to control the environment, to produce better machines, better use of minds and natural resources. But in point of fact there weren't any big advances in technology. Control of the environment until the 19th century, a very rare example occurred in the 18th century when Benjamin Franklin on the basis of research and electricity invented the lightning rod. But by and large, the sciences did not really effect technology until after the great industrial revolution.

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Antonello: Was the scientific revolution important for the industrial revolution?

00:06:59:07Þ Not. The people who produced the industrial revolution, by which we mean usually the mechanization of the spinning industry, the invention of the steam engine and its application as a new source of power, and the beginnings of the factory system and mass production. These were people who are artisans by and large, who didn't know much about science. The real influence of science on technology came only later, probably beginning about 1830, and reached its first major highpoint with chemistry in the middle of the 19th century. But before that, the effects are very marginal, very minimal, one works very hard to find real examples.

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Antonello: Was the technology of the industrial revolution autonomous?

00:08:03:23Þ Well,if any revolution is autonomous, the industrial revolution is to a very large degree. On the other hand, I think it has to be remembered that the industrial revolution was a product also of social forces, of the need to make better use of human labor, for example. To have people who are congregating into cities, this is the time of great population shift. To be able to use these people, cottage industry didn't work so much anymore, so there were various forces that were acting in a sense that one doesn't like to say it was autonomous. On the other hand, surely if you look for the real internal motivating forces, they didn't come from the applications of science at first, they came from the people who were skilled artisans of improving the way in which they did things.

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Antonello: Where do innovations and inventions come from?

00:09:27:15Þ Where does invention and innovation come from in technology? Well that's a extremely interesting point, many people write about the importance of technological innovation, but for me, I've always been much more interested in how innovation is possible. One can see everywhere the fact that people don't like innovation. My theory is, that what's astonishing is that we get any innovation at all. Let me just give you a couple of examples: The suit that I'm wearing has a button hole here, I use it for my watch chain. Originally it was meant for a button on this side, the button is gone, but the technology continues. There are buttons here which are functionless, the tie which is decorative, which I happen to wear, most people have given it up, has lost its function because the collar button's underneath. When the first automobiles were made, they were horseless carriages. Naturally since the horse was in front, they put the engine in front. Originally, horse carriages had a little socket on the side where a whip was put to whip the horse. Those first automobiles, horseless carriages were made with whip sockets, eventhough there was no thought of having a horse because nobody thought, everybody had always made it that way. Tried and true, we say, well tested.

00:11:09:12Þ So the miracle is,
to me, that people really do innovate. There was a time when in the practice of medicine, if you knew a doctor who was innovating and experimenting, you wouldn't go to him. You would be afraid he's going to try something new on me. Now today, we want to say, I want the latest. The dernier crie, that's for me, I don't want those old fashioned remedies. But that's a very different attitude for most of history. So we have a real problem with innovation, as I see it. How does it actually come about at all?

00:11:50:16Þ And then the second thing we have to notice is, of course there are some clever people. And they say well yes this is tried and true, but there's a..maybe I can do that justa little bit better. And we know that all great inventions that have come in, the horse collar, which most people have seen a horse. But a horse collar is a way of attaching a horse to a wagon, so that it pulls from down below with its full force. The Romans didn't have it, they harnessed a horse by tying a rope around its neck. It could pull with a maximum power of fifty pounds. In the late Middle Ages, the horse collar came into being, and for the first time a horse could pull with more force than a man. That's the kind of great innovation of technology that we have that changes all of society. And in the industrial revolution there was apparently a spirit in the age, and no one that I've ever seen has a satisfactory answer to where that actually came from. But a number of people in different places began to innovate and it caught on. And of course as you know, what then happened was that people were willing to put money into it, and then you had entrepreneurs building new industrial system and our so called industrial revolution was launched.

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Antonello: What's the relationship between science and technology beginning with the industrial revolution?

00:13:39:15Þ The relation between science and technology, as I see it, from the industrial revolution to the present, has followed several very interesting paths. In the beginning, let us say from about 1800-1830 or 35, technology did much more for science than science did for technology. The steam engine posed problems which produced the new science of thermodynamics. Carnot and the Carnocycle(?) were based upon the steam engine. During that period you would be very hard put to find anything of equal importance where science really was of great importance to industry. Except perhaps in some parts of the chemical industry. The manufacture of gun powder, the use of particularly, in-organic chemicals.

00:14:50:22Þ In the next thirty or forty years, from say 1830 up until about 1860 or 70, we have a beginning of a shift. A shift in which a number of major inventions are beginning to be based on science. We have the rise of the dye industry for example, which changed the whole nature of society in parts of the world where the primary crop along the Mediterranean, from Spain to the Middle East and through much of India, had been the growing of plants for dye purpose. Within a matter of a few decades that disappeared entirely, and this became food producing country, the whole economy changing. I mean that's the new influence that science has on technology, yet in the same period we have enormous inventions of consequence, that are based on mechanical combination. Agricultural machinery, the reaper,

the binder, which changed at least in America the great plains agriculture from small scale operation to large scale agriculture. Probably for most people in their lives, in the second half of the 19th century, the impact of science on technology would be primarily characterized by electricity and electro magnetism. The age of communication, the telegraph, the cable, eventually the telephone, radio, television, everything controlled by electronics and the computer. I mean here we have a whole line of development of industry that depended entirely upon science. And all that depends upon it, the effects of society, of an information explosion, and all that that carried with it.

00:16:55:09Þ Here then we have a new look, which entails that industry, technology sets problem of great interest for the scientist. And even begins to support specific scientific research aimed at solving technological problems, and achieving technological goals. That's the new look, and that's the thing that we live in today, where most innovation, or at least a large part of innovation in technology is, if not derived from science, is driven by science. But at the same time I think it would be a mistake, as often you see in the more lurid accounts in the newspapers, to think that all innovation is science based. That the man who has now no knowledge of science, can do nothing. We have the ball point pen for example, which was invented by a clever mechanical engineer, not necessarily a man with high science training.

00:18:13:02Þ If you read the more lurid accounts in the newspapers today, I think you would get the impression that all technological innovation is science based, but this isn't really the case. There are many innovations which come as they have always in the past from people who are very clever mechanics, clever with their hands. The paper clip is one example, the ball point pen is another invention which don't really necessarily depend upon having any scientific background. There are many of these in many parts of industry, at the same time, I think it's fair to say that the majority if not based on science that is some degree in contact, or as we like to say, science driven.

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Antonello: What is the difference between science and technology?

00:19:35:00Þ Well the difference...there's a great and interesting difference between science and technology. Many people think well aren't they getting to be the same and the answer is no. The results may deal with the same subject, the real difference is, not so much in science and technology, as it is in scientists and technologists. If you put a group of scientists and technologists together, and you're interested in a problem such as super sonic flight. The technologists say, how many years will it take, how much will it cost,

what kind of metals can we use... the scientists says, this is a very interesting problem, what principles are we using. So there is a huge difference of 180 degrees in the point of view, and therefore, where they use the same knowledge, they use it differently, and they think differently. And I think perhaps one of the most interesting aspects therefore of 20th century civilization, as we reach the final decade of it, is that people with such really disparate points of view can nevertheless work harmoniously toward the same end.

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Antonello: What is your definition of technology?

00:21:30:05Þ Well my belief in technology is, that technology is a system. And it's a system in which you use objects and programs whereby you use those objects are for particular well defined ends, that means to make something, to do something, to use something, whereas, it seems to be that the goal of science still is to try to understand in the most fundamental way we can, every aspect of the operation of the world around us. That includes both the natural world and the artificial world created by technology. For example, if technology creates a mechanical system, made up of metals which act in a certain way, that raises problems of the nature of metals and solid state physics which become scientific problems. And that is where I see a very close interrelationship, as well as the one in which, in order to produce certain parts of technological systems you have to have fundamental scientific knowledge to apply. Otherwise, you can't build the system successfully, or make it operate successfully. So there is this back and forth exchange between the two, but the goals are really very different. What you reward someone for in technology is that that person produces a social result, which can be a new way of manufacturing something, the cure of a disease, a new way of growing plants, a new way of harvesting the plant, a new kind of metal for a given purpose, a new way of sending power, a new way of communication and so forth, but the reward for the scientist on the highest level is independent of whether what he does has any immediate practical use or not. You reward the scientist because what he's done is revolutionary, because it's fundamental, because it embraces a lot of subjects and changes our point of view with regard to them.

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Antonello: Can you talk about revolutions in science?

00:24:24:15Þ Whenever people talk about revolution and science, the discussion usually breaks into two parts. One part is, should you really talk about revolutions in science, since these revolutions are

not exactly the same as the political and social revolution which we encounter when we read our newspaper. And the other group says, yes these are similar, and the word should be used, it isn't necessarily a source of confusion. My point of view is a little different, my research has shown that almost from the very beginning of the scientific revolution, there was a recognition among scientists and nonscientist, that a revolution had occurred. And they saw in this an analogy that the very fundamental changes which only later became associated with political revolution. In short, the earliest revolution in modern time, that we know of, if we think of that word in it's deepest and fullest meaning, occurred in the sciences. With the work of Harvey, Galileo, Kepler, Lavoisier(?) and the chemical revolution, the great Darwinian revolution, and more recently the Einstienian revolution, or the great revolution that has produced our knowledge of molecular biology and human genetics.

00:26:05:01Þ Of these revolutions almost always involved a break with the past, a rupture. So there is this same kind of violence that we associate with political revolution. There is at the same time a shift in the sources of authority, from people who are established in the field, the young revolutionaries who are setting up a new version of the subject, and so on. In many ways the parallels are exact, in my opinion. Having said that, I should add, that we overuse the word and that's one of the reasons people object to it. A toothpaste that is new is called a revolution. The advertising people, the newspapers have cheapened the currency, but I still think we shouldn't throw out an expression that we've used traditionally, which does conjure up a very important kind of image, namely that on the one hand you have conservatives who believe in old ideas with old textbooks, control of the funds in the academies. And you throw them out and put in the new people, it's a very violent revolutionary act, that sometimes has by psychologists been compared to murdering ones own father, getting rid of ones intellectual progenitors.

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ANtonello: Did the concept of time change with the scientific and industrial revolutions?

00:27:52:07Þ Well the history of time, as I see it, has undergone a number of revolutions. The chief one probably being the invention of time somewhere in the distant past. In modern times, time became very important at the moment of the scientific revolution, and it did so because it was quickly recognized that the three fundamental units for all science are mass, length and time, and associated rythem of force. You had standards of mass and standards of length, you then had to have standards of time, and as science dealt more and and more with phenomenon that required great accuracy in measurement, the definition of time and invention of more and more accurate time keeping instruments, became a very

fundamental part of scientific advance. And in this sense there certainly has been an enormous revolution as time has become more and more exact. Now the corollary to that, from the point of view of general society is that we also have become a very time directed society. I don't know exactly when that occurred. I have a theory that there were two great factors involved, but I'm not really an expert on this subject. One of them certainly is the railroad. To have trains that are running, you have to have an exact time system, or you can't have a schedule, or two trains will meet on the track going in the same direction, you know..., and that's the end of it.

00:29:58:01Þ The second thing is, that after the industrial revolution, with the development of the factory system, it became necessary for all the people who were parts of this same factory to start work together, and therefore, to finish their work together. And therefore, you had to have clocks in a very carefully, time driven society. Now the hour was invented by the Egyptians, but the Egyptians had a changing hour, because it divided equally daylight and nighttime. And these changed throughout the season. Though it wasn't a universal time that you or I or anyone else could know about, but only the priest could know it. What I'm talking about is public time and socially therefore, it's public time which is the new innovation, an exact public time where the hour and even the minute is of consequence. And we can see the difference between that new time and the old time by looking at any of the cathedral clocks in Europe where they only have.....

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00:00:39:09Þ We can see the difference between the old time and the new time, by looking at the clock towers in medieval and renaissance buildings in Europe, where the clock has only one hand for the hour, because it wasn't accurate enough for the minutes to make much sense. And when we compare that to having to come to a factory and punch a timeclock, where if you're five minutes late or ten minutes late, you get docked in your salary. Or where the train isn't running on the minute rather than the hour, throws off the whole schedule of all the other trains that are running on those same tracks.

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Antoenello: What is the relationship between war and technology and war and science?

00:01:36:11Þ The relationship between war and technology, is of course today a very close one. Among the demands that society makes on technology, those produced by the so called defense industry rank very very high. And certainly they produce a

large amount of technological innovation energy in trying to imagine what can be done, or what someone else might do for which you have to have supposedly a defensive system. Everybody is aware that this is also an extremely expensive process, because it requires special demands which don't exist for ordinary civilian technology. Let me give you a simple example, a military device usually has to be extremely accurate, but to operate for a very short time, as in the case of rockets. A civilian device is usually made we hope to last a long time, and we don't care whether it's always perfectly accurate, as long as it's accurate most of the time. Therefore, we have a different technological demand for the military than we do for the civilian technology.

00:03:20:13Þ One of the great problems that all the people who have real conscience and insight are concerned about therefore, is whether you could have any dual use technology. The same technology to serve for military and civilian purpose. And in most cases this is very difficult, and not at all easy as it sounds.

Now the relation of science to that military technology is based primarily on the fact that if you're anticipating in your military technology what some other country with its military technology might do, you have to have forethought. You have to not only imagine what present day technology has as its possibilities, but what kind of possible future applications can be made of the most abstract science, guessing ahead 10, 15, even 20 years. But here the technologist himself is of little use, because he has no understanding of where science may go, and his guesses therefore are not very educated guesses. That's one of the chief roles that the scientist has other than the normal link of science technology, which you have in every aspect of technology, whether civil or military.

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Antonello: Is there spin-off technology from the military research?

00:05:05:16Þ Well I'm not really much of an expert, as far as I can see the spinoff from military technology to civil technology is generally small, it's bigger in some areas than others. I think one of the areas in which one has seen a real spinoff has been in the aircraft industry, certainly the development of large jet aircraft came first in the military and then in the civilian sector. But by and large, the single object that people talk about more than any other is the microwave oven. Well when you think of the enormous radar and microwave technology, to get that little microwave oven as the spinoff is very very little. And the likelihood is that the development of microwave technology would of produced the microwave oven in any event. As I said, what of the difficulties with spinoff is that if you think of the goal out of particular object in military technology, almost all of the parameters are entirely different from those that we

would want in civilian or civil technology, and that's the big problem.

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Antonello: Can you talk about the computer...?

00:06:58:11Þ The computer as it has developed, has had an enormous input from military funds. And one of the reasons for that is, that among the primary original computational needs that is actual making of tables, there were three or four areas of enormous importance that have been traditional for at least a hundred years or more. One of them was insurance in the production of actuarial tables. A second was in census, dealing with all the data that one collect, and therefore, that is clearly government. A third area was astronomy, and astronomy was supported by government, and particularly by the military because of the use of navigational tables. And then finally a very important area was the production of firing tables for artillery, ordinance. So there are certain areas where one would expect that the military at the government in general, and the military in particular would be interested.

00:08:22:10Þ Now what happened, that the computer was born during WW2. One would expect that there might therefore have been some military input. What is much more significant in my opinion is, that when the computer was developed in the years immediately following WW2, it turns out that it needed large input of government funds. No private industry was up to supporting it. Government funds were needed for the research, for the development, the manufacture, and finally the purchase and use. Where was most of the government money after WW2? In the military. So it's only natural that a very expensive technology that would be of use to the military as well as the non military, would have had a tremendous military input. This clouds the issue a little, because one might think otherwise that the reason for this is, that the computer has something special for the military that wouldn't be useful for the nonmilitary, that's not so. It's just that that's where the funds were. We have a very interesting example in England, the Lion's Tea people developed, made a computer for civilian purposes. For running their business of supply, these hundreds of tea shops with hundreds of different items, and keeping all those orders straight. They were able to make one computer for that and they started to make others and introduced a company, without any government support whatever. It couldn't get anywhere, there weren't customers. There weren't enough other people in industry that keep supporting the movement of that without some help from government. And the help from government for industry, generally, at least in western countries, has not been great, except in the areas of public health, which this wasn't related to, or military.

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Antonello: Do science and technology require govt funding for development and research?

00:10:57:19Þ Is it necessary for modern technology and modern science to have support, financial support on a large scale? The answer is yes, it's extremely costly. We know that even in technology such as computer technology a mammoth company like IBM was not able on its own resources to support the development it needed to produce some of its great computers. Therefore, appeal was made to government. Much of modern science is very costly, it cost more than industry or private individuals or endowed universities, educational systems could afford to pay, the only obvious source is government. Now within the government, in democratic countries, money for peaceful purposes is only available in small quantities. Big money often is associated with military purposes, where the direct or indirect military people often support what looks like ordinary science, because they feel that having a healthy scientific activity eventually will be beneficial to them.

00:12:21:06Þ Therefore the answer must be, that in certain areas the funds will come from some military or some other government organization which has that kind of funds that it can spend. It's not because the technology must come from that, it's that the support must come from it. But that's not a function of the nature of the instrument so much as the structure of society.

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Antonello: What are the social and economic implications of this?

00:13:29:03Þ Well, I would like to talk a little bit about the technology in relation to the civilian economy, and civilian posture.

It has two, I think, has at least two major aspects. The first is, that there is no policy in the US at the present time, it's a loose structure, go where it can, do what it does. There's no clearly marked defined policy for the development and research and direction of technology. Even on the part of industry as a whole. There's certainly is no question that a large amount of our innovative technology, and of our resources are being devoted to military technology, which by and large is not saleable to other countries. Therefore, we are devoting an enormous amount of our resources to what (???) defined clearly marked as nonproductive technology in that sense. My own personal belief is, that this is certainly at the basis where at least one of the major, if not the major factor that's related to the decline of America in world market. At the same time other people argue that from the internal point of view of the American economy, that this does produce a large amount of jobs, that there is a self sustaining group of people employed in these defense industries, and would they be equally employed if all of that effort, or a large part

of it, were directed to the civilian sector. I'm not enough of an economist to answer that. I think there would certainly be dislocation at first. But it seems to me that over time I can't see that this would be a major factor, but that's a very personal opinion. I haven't got much more time.....

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Antonello: ..the idea of progress?

00:16:13:06Þ Well you ask me about progress, and progress is a very, very loaded word. It gets you always into big arguments. Are people any better today than they were a thousand years ago? Certainly the wars are more sanitary, but are there less wars? Probably not. I don't really know, I've never made a count of that. Is society better, are we making progress? My own feeling in the matter is that I have never seen an easy standard whereby one can tell. But in the sciences, and in technology we have a very definite answer, yes there is progress. Every student in high school who graduates with an honors course in physics today, probably knows more physics than Isaac Newton. And anybody who read the books of Galileo and understood them, knew more about the physics of motion than Plato, Aristotle, Ptolemy and all the Greeks combined, eventhough they weren't smarter. There's a real test of progress. We can explain things, we can predict phenomenon more exactly. We can analyze and find out the root causes of events which to our ancestors were fortuitous without any seeming pattern. These are real instances of measurable progress.

00:17:59:06Þ In technology, including medicine, we've conquered certain diseases. Smallpox is practically eliminated. One can say, it's not that the world is healthier, but that we have the means of having a much healthier world universally, then would have been possible 500 years ago or 100 years ago. So for that progress has meaning. Transportation, we can move things much more quickly. We can transport things which in the past were untransportable, because it would take too long, or because we didn't have stable transporters. So in technology and in science, progress really has meaning. But when we come to any kind of human activity, I've never seen any absolutely convincing argument about it. Yes, of course, I think one can say, that by and large many people today if you want to deal in percentages, in certain countries are certainly better off than any percentage you could have found that was the equivalent in any other country and any other culture. But it isn't universal, and how can we say that we have progress in terms of our living, if we think only of the people who are the most fortunate without thinking of all the people who are less fortunate. Yes we have progress, we have the means, but the situation, I don't know. So I feel that only in my own special area of science and technology, can we say that progress has a real and obvious meaning which almost all intelligent people would agree to.