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THE IMPORTANCE OF THE HISTORY OF SCIENCE IN INTELLECTUAL FORMATION

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What we call 'scientific knowledge' has two distinct facets. In the first place, the term 'science' refers to a collection of known facts which taken together give mankind a great power over nature. This is the side of science which is at once most visible and best-known. It allows us to carry out a vast range of projects, and it is thus part of the foundation of the modern global economy. Science in this sense has a place at the heart of our civilisation, a place which it will without doubt retain in the century which is before us.

The second aspect of science is something less well-known to politicians and to the public at large, but of great importance in the formation of scientists, namely, the scientific method. The scientific method is what allows science to develop successfully and to be put to practical use. Thus it is not enough for trainee scientists to gain a knowledge of what has already been scientifically established; they have above all to gain an understanding of the methods which will permit them to establish new truths and to envisage new technological applications of what they already know. This means developing a certain mentality, which we can call the scientific mind. A person with a scientific mind will know how to make the most of his rational gifts, yet at the same time be able to evaluate critically the use which he does in fact make of them.

This is the background to the remarks I shall be making about intellectual formation. There is one point in particular which needs to be stressed, namely the place which history must have in the teaching of science. The history of science is a branch of history which should not be neglected.

1. What is the 'History of Science'?[1]

1. The study of the history of science developed very significantly during the 20th Century. The work that has been done in this area allows us to determine more precisely what we mean by the history of science, and what ground this discipline covers. It is in practice the history of the natural sciences plus the history of mathematics. It is only rarely that the human sciences come into consideration in this connection. Some people would give the term 'history of science' a stricter sense, and mean by it just the history of the natural sciences. Nevertheless, the human sciences and mathematics share a common method with the natural sciences inasmuch as they are also rational acticivities.

The history of science as it has developed in the 20th century has two principal concerns. The first is to understand the way in which scientific knowledge progresses. The second is to understand the notion of science itself, which involves the questions of what methods are truly scientific and what kind of knowledge science actually offers us.

The studies that have been carried out in this field show how hard it is to separate the history of science from other branches of history. For example, medicine is at once a science, a technique and an art, and its history is bound up with the development of many different sciences.

2. The history of science obviously includes many different facts about things which happened at various times in the past. Yet simply compiling a list of such facts does not suffice for genuine history. For this, it is necessary to bring out the relationships between facts, indicating where there is continuity and where there is a break with the past. The history of science has thus to take into consideration the process by which science comes into being, that's to say, the various stages of its development. It's sometimes necessary in this connection to take into account the personalities of scientists themselves, in order to understand how they came to their various conclusions.

Not only must the history of science talk about 'facts', it must also talk about 'results', or about the diffusion within the wider scientific community of a particular piece of research. What happens here is that something which was the property of one individual becomes a sort of 'common good', and in the process gains a certain 'objectivity'. As soon as a result is published, it no longer belongs exclusively to the man who discovered it: it is now in the public domain.

[1] Cfr. François Russo, *Nature et méthode de l'histoire des sciences*, Paris, 1983.

What does this imply? It implies that other people may now find a significance of their own in what was discovered. They can adopt a given result for their own purposes and put it to uses which were not those of the original researchers.

3. This gives rise to a third consideration, namely the way in which the very notion of science changes as its methods evolve. What precisely is the sort of knowledge at which scientists are aiming?

Studying the history of science makes us see a dimension of intellectual work which is sometimes neglected, namely the cultural and spiritual context in which work is done. What appears to be insignificant at one moment can be of great importance later on. Thus Darwin would certainly have known about the work done by Mendel, but he didn't take it into account. Mendel's work didn't answer the questions which Darwin was actually asking, as their approaches to their subject were so different.

2. The Development of Science

One of the benefits of studying the history of science is that it helps to free us from a naïvely 'progressive' understanding of science. According to this view, science is supposed slowly but surely to have gained possession of the whole field of human knowledge; everything solid or well-founded in human knowledge is supposed to have come about thanks to the scientific method. In fact, history shows us that the development or progress of science is far from being a peaceful or uninterrupted affair. It is on the contrary an *adventure*, a human enterprise which is subject to the same vicissitudes as any other human endeavour.

2.1. *The Development of science: a fitful affair*

If the development of science were perfectly regular and harmonious, it would be a continual advance in which every result allowed one to proceed still further in the same direction. In reality, we find on closer inspection that science necessarily implies breaks with the past. This is what gives rise to the expression 'scientific revolutions', though the phrase is perhaps overly strong. Furthermore there is sometimes a long gap between the moment when a new discovery is made public and the moment when it is actually taken into serious consideration. For example, Saccheri published his work on non-Euclidean geometry at the beginning of the 18th century, but it wasn't looked at seriously for another hundred years. His work was easily available and yet it simply failed to generate any interest.

Another aspect of the fitfulness of scientific progress is that some periods seem much *richer* than others. During certain periods there is a great creativity about scientifc research; at other times science seems as it were to be in hiding. For example, in the first few years of the 20th century, we find Planck's work on quanta in 1900, and in 1905 the three principal theses of Einstein, namely those on Brownian motion, special relativity and photons. Likewise, between 1925 and 1930 we find the development of quantum mechanics, whilst in 1932 some very successful investigations are made into the nature of matter, with the discoveries of the disintegration of matter and of the neutron. What is is that makes one short space of time so extraordinarily rich? It is hard to say. Sometimes, of course, it can be the opposite which happens. In the Middle Ages, for example, there was not a great deal of scientific discovery: that was to come in with the 17th century, during which the foundations of modern science were laid.

Again, not all disciplines advance at the same rate. Biology, for example, developed much more slowly than physics, and even within a given discipline, the various parts do not always progress at the same pace.

A final point: the progress of science is also fitful in a geographical sense. We find that certain great centres of science – Athens, Alexandria, Bagdad, Seville, Oxford, Paris, Padua etc – flourish for a while and then decline.

2.2. *The search for greater precision*

Scientific discoveries, when they are first made, are not always so clear-cut and precise as they may appear to be later when they have found their place in a well-defined system. This causes problems for the historian of science. In the initial stages, ideas are often vague and ill-defined, and perhaps ambiguous, both in the mind of the scientist and in the experimental application which he makes of them. Yet it is precisely these ideas which turn out in the end to have been fruitful. Even when they are made more precise later on, we shouldn't forget what a rich significance they had originally, as it was precisely this that led scientists to interest themselves in them and to benefit greatly as a result.

Now scientific precision is acheived only gradually and often clumsily. The history of science shows us many a strange mixture of truth and error. True and false ideas are found together not only in the same science and in the investigation of a given question, but even sometimes in one and the same scientist. The founders of modern science themselves, men such as Kepler, Galileo, Descartes, Newton and Leibniz, were not immune from this law. The erroneous views which they all held on various matters didn't stop them from greatly furthering scientific knowledge: but their erroneous views had eventually to be criticised. Thus Newton, for example, sought to give a scientific account of the stability of the solar system, but at the same time put forward a whole host of speculations about divine activity at particular points in the world. It was not until the end of the 18th century that Laplace was able to give a fully satisfactory account of the planetary movements. Obsolete ideas can sometimes get in the way of scientific progress – witness Galileo's attachment to the idea of circular motion or Sadi Carnot's belief that calories were a certain kind of liquid.

2.3. *Conflicts of approach*

The history of science also shows us that one and the same question can be approached in quite different ways by different scientists, though this doesn't necessarily stop them arriving at the same conclusions. The best example of this is perhaps that of quantum mechanics. The formalism worked out by Louis de Broglie was quite different from the one worked out by Werner Heisenberg, but both of them give the same results. Planck and Einstein, likewise, approached the question of the quantum from very different perspectives.

Sometimes this varierty of approach causes conflict. One thinks of the battles between geocentrism and heliocentrism, or again between the followers of Descartes and the followers of Newton. Later on there were the battles between evolutionists and those who maintained the stability of species, and later still between the realist view of science and the conventionalist view. This raises the question of how a theory is to be proved.

We find in the development of science two opposing forces. On the one hand there is the urge to gain a fuller understaning of one's subject. On the other hand there is always a certain resistance to what is new. This resistance to change no doubt arises from the scientist's own attachment to certain opinions. He is used to thinking in a given way, and it is difficult for him to change. Gaston Bachelard describes this as the 'epistemological obstacle'.

What can we conclude from these brief remarks on the development of science? The historical study of science enables us to recognise the limits of scientific work. In particular it shows how science is simply one human activity among others: like all human activities, it is exposed to chances of every kind.

All this leads us to ask more fundamental questions about the nature of science itself. What makes something 'scientific'? What precisely do we mean by a rigorous 'scientific method'?

3. What is science?

Scientists sometimes give the impression that there is no difficulty about knowing whether or not a certain piece of research is really scientific. It might seem that everyone was agreed about what the relevant criteria are. After all, without some idea of these criteria, we wouln't be able to talk about science. Yet in fact our notion of science need to be rendered clear. As long as it remains ambiguous, it inevitably gives rise to misunderstandings and even to polemic, as happened recently with regard to 'water-memory', or during the Sokal affair.

Why does it sometimes prove difficult to agree on what counts as science? It is doubtless because science is made up of a variety of elements, and, as the history of science reveals, the importance accorded to these various elements has changed over the years. This also helps us to understand the difficulties which science is currently experiencing in certain countries: the very notion of 'science' is not understood in the same way in every culture.

A last point: the criteria which render something scientific vary according to the various branches of science.

3.1. *Science and pseudo-science*

Scientists today are sometimes confronted by what they consider to be *pseudo-science*. In France last year, this led to a very interesting argument at a certain university. A student who was known for her astrological publications submitted a doctoral thesis in sociology in which she described these publications as scientific. Scientists and other academics protested vigorously, considering astrology to be no more than a pseudo-science.

In fact, things like astrology have a complicated relationship with science. Sometimes they may be examples of a pre-scientific sort of knowledge which can in fact serve as a basis for science itself. It was in this way that alchemy was related to chemistry or ancient astrology to astronomy.

But they can also be the result of a hi-jacking of science, as is the case with certain religious sects which claim the title of science for what they practise in their healing-sessions or for their vision of the universe. The study of history enables us to make an impartial judgement of these matters and helps us to establish sure criteria of what counts as science.

3.2. *The basic criteria of science*

There are a certain number of criteria about what counts as a truly scientific approach to the world on which the whole scientific community is agreed.

1. *Objectivity*. All scientific work pre-supposes a separation between the scientist and his work. Objectivity is guaranteed by the fact that independent observers can obtain the same result; observations must be *repeatable*.

2. *Precision*. Observations must be precise, as must the words in which they are described, whether it is hypotheses, concepts, laws or theories which are in question.

3. *Attention to detail*. In his analysis of the facts, the scientist must endeavour not to overlook any aspect of what he observes.

4. *Universality*. Science does not seek just to ascertain individual facts, but also to draw from them generally-applicable laws. This requires an abstract language capable of expressing the ‘models’ which scientists use to explain their observations.

5. *Refusal of occult explanations*. The scientific mind does not explain its observations by recourse to occult causes, for example magic, or agents which lie outside the natural world, such as spirits, genies, or demons. This attitude implies a certain detachment from the world of religion, though it fits well with the acknowledgement of a unique, transcendent God who is not a part of the universe.

6. *Consistency*. A given explanation must be susceptible of incorporation into a more general theory. There can never be contradictions between the various parts of science. The scientific endeavour implies a desire to unify human knowledge.

7. *Regularity*. Science seeks to discover some regular pattern in what it observes, and it is this pattern which needs to be highlighted by the scientist.

8. *Open-mindedness*. The true scientist always has a critical attitude towards what he receives from the past, wishing to verify for himself the truth of traditional views. An argument from authority is not enough for him.

9. *Desire for constant improvement*. To be true to itself, science must always seek to be more and more closely shaped by the real world.

These criteria of genuine science are of course very general. They apply not only to the sciences of nature, but to all intellectual endeavour. We should also add that contemporary science is based on additional criteria, stricter than the ones just cited.

3.3. *Some more specific criteria*

In addition to the nine criteria given above, there are others which govern a more precise scientific method. It is in recent years that these stricter criteria have been clearly expounded. Thus:

1. Experiments are possible which modify nature to a significant degree.

2. All concepts used are subject to a full analysis, so that they may be 'operational concepts'.

3. Principles, ideas and theories must be capable of being measured against real facts. Thus Popper introduced the negative notion of falsifiability to explain what counts as genuine verification.

4. Knowledge is not to be understood as yielding certitude – this is a Cartesian ideal. Instead, it gives us greater or lesser degrees of probability.

5. The kind of measurement used has to be precise and clear.

6. Many notions hitherto the preserve of theology and metaphysics have to be considered objects of scientific thought. Examples include the formation of the universe, the formation of living species, the generation of living things. These facts which were previously explained theologically are now objects of scientific study. At the same time, it's important to recognise that such study is just one of the activities of man's intelligence, and that it doesn't exclude other approaches to these problems.

7. The notion of final causality is to be excluded from scientific discourse.

8. The process of mathematisation must be allowed to increase and become ever more refined. Mathematical objects, in fact, are no longer limited by the ideas and images implied by Euclidean geometry.

9. Experiments may be more various than was previously the case. There is a place, for example, for so-called 'thought-experiments'.

10. Statistical laws are to be accepted on the same footing as the strict laws of classical mechanics. It seems that theoretical physics, dominant as it is, leaves a place for the sciences of life.

This brief discussion of what counts as genuine science shows how useful the study of the history of science is. It enables us to see how scientific criteria have gradually become more precise, and how these criteria may be variously arranged and emphasised, thus giving rise to various ways of thinking. The distinction of science and pseudo-science is particularly important in the formation of the scientific mind.

4. Human formation

The remarks we have made about the scientific mind show how the study of the history of science can help promote a well-rounded human formation.

4.1. *Relations between various branches of knowledge*

What has been said about the training required by the scientist, in particular the distinction between science and pseudo-science, may serve as a general invitation for us all to consider what is the exact relation of our own discipline to other disciplines. It can be humbling for us to have to admit how very limited our own discipline inevitably is; yet in so doing we become more ready to learn from others, and to accept other points of view. We also become more cautious about demarcating the various parts of human knowledge too absolutely. History shows us the troubles that can be caused by inadequate definitions of different disciplines. One need only think in this connection of the arguments put forward in the name of religion on such questions as geocentrism, the history of the world, the gradual development of each human being, the evolution of living things and the origin of mankind. Unfortunately, as the influence of various fundamentalist movements demonstrates, the arguments in question are still to be found today.

Again, history helps us to avoid the mistake which is sometimes termed ‘scientism’, a philosophy according to which only scientific knowledge is truly worthy of the name of knowledge. History shows us how much the criteria of what counts as science have changed over the years. This should dissuade us from supposing that science holds a monopoly on the truth.

4.2. *The just appreciation of one’s own area of expertise*

The foregoing remarks about the history of science may not only prompt us to revise certain opinions about scientific work; they can also bring us to a better understanding of our own field of expertise, whatever that may be. The scientist, after all, is well aware that his knowledge is always in a somewhat precarious condition. He knows that he mustn't treat it as something absolute. This doesn't mean that he lessens its value, simply that he sees it as a part of a wider scientific effort. In this way, he is better able to appreciate the science which is still in the process of development, as well as the science which has already established definite results. The development of science is far from being a purely deductive affair – it calls for imagination and creativity, and even for that sort of 'contemplativeness' which is to be found wherever there is a genuine desire for knowledge.

History shows us that to judge of the truth of a given scientific proposition, we need to be able to place it in a broader context. In the life of the mind, there are certain fundamental options which govern everything else. An awareness of this allows us to see more clearly what intuitions and convictions have guided a particular piece of research.

4.3. *The foundations of science*

We can appreciate the greatness and the fruitfulness of science only when we truly understand its limits. The first of these limits comes from within science itself. For the exactitude and objectivity of science, and the clarity at which it aims, presuppose that the constitutive elements of a given scientific endeavour are properly defined. Yet when we seek rigorous definitions of all relevant terms, it becomes clear that science relies on certain notions which it is not able to define by itself – such things, namely, as force, space, time, matter, energy and so on. All these notions come to science from outside. They depend upon certain basic intuitions, upon that 'first philosophy' which is coaeval with thought itself and of which we are all the heirs.

In this way, science discovers its own foundations, and is thus also brought into contact with philosophy. Just as there was once a time when cetain great thinkers, men such as Descartes, Pascal and Leibniz, could be both scientists and philosophers, so even today every scientist has some philosophy upon which all his research is founded. The study of the history of science makes one aware of this link between science and philosophy. It is interesting in this respect to compare these earlier periods in the history of scientific thought with scientific education today, where the aim is generally to pass on those results which will help the student to gain a professional competence.

A scientific training which takes into account the various stages in the history of science thus enables the student to situate his discipline more successfully. He can learn to see what relation it has to the philosophy of nature, to the study of man himself, and to God.

4.4. *Science and reality*

The wish to come into contact with the real world is an important part of any scientific endeavour. As the criteria of what counts as genuine science show, particularly those which have to do with objectivity and experimental observation, the aim of the scientific method is to give us a more complete understanding of what exists independently of man. No doubt the object of science is something constructed by the mind: the scientist must not take the object with which he has to do, and which he represents by mathematical language or by general concepts, for reality itself. But his intention is always to come into contact with the real world, the existence of which he takes for granted.

Science thus aims at *truth*: and truth is defined by philosophical tradition as the agreement between knowledge and the world exterior to the one who is seeking to know. The scientific endeavour is therefore a movement towards a horizon which cannot be crossed.

Conclusion

In the context of this symposium of the Pontifical Academy of Science, which has education for its theme, it was important to stress that scientific training involves some intellectual elements and some practical ones. Nor should we forget the relations between the people who carry out the work of science, of which work education itself is one part.

Although teaching obviously includes the passing on of information, its aim is also broader than this. This fact is well-reflected by a change in official nomenclature that took place in France recently. What was formerly the 'Ministry of Public Instruction' has become the 'Ministry of National Education'. In other words, the formation given to children and teenagers is not simply to be reduced to a handing-on of items of knowledge; it must have a broader aim. Education has to foster all the various human qualities which will make for an adult life worthy of the name.

The study of science will obviously have an important rôle to play in this context. To complete what has already been said: a place must be found for the history of science within the teaching of the sciences themselves. This seems to me vital if the abstract and theoretical knowledge contained in the sciences is to be communicated in a way that takes into account the student's need for a well-rounded human formation. It is not during history lessons or philosophy lessons that this teaching should take place, but actually as a fundamental part of the scientific teaching itself.

Such an undertaking would seem to me to have a twofold value. In the first place, it would help students to gain a more accurate understanding of the true nature of scientific propositions. Secondly, it would give them a new relation to the scientific knowledge which they possess. One can add also that the study of history, whilst it may 'relativise' knowledge, nevertheless helps the student to develop a certain sympathy with what is unfamiliar. In this way he is better able to appreciate realities which encompass or transcend his own limited area of expertise.

Thus the remarks which I've made in this communication about the importance of the historical point of view are not limited solely to the history of the natural sciences. They also apply to the human sciences, and they have implications for the way that we relate to *any* branch of knowledge. This is particularly true for theology, for the progress which this has made in modern times is bound up with our understanding of history, as the case of biblical studies shows. It is the historical method which allows Christians to read the fundamental texts of their faith in a way that benefits not only their intelligences, but also their moral and spiritual lives.