SCIENCE AND THE CRAFTS IN THE ANCIENT NEAR EAST

R.J. Forbes

Introduction, by André Wegener Sleeswijk

The title of the inaugural address (translated from the Dutch) which was delivered on June 30th 1947 at the University of Amsterdam by the newly-appointed professor extraordinary Robert Jacobus Forbes (1900-1973), succinctly describes its theme, the relationship between the crafts and the sciences in ancient Mesopotamia, Egypt, Greece, the Hellenistic city states, and the Roman Republic and Empire. The address was published by Brill of Leiden. The translation which follows after this introduction is the joint effort of H.F. Cohen, A. Wegener Sleeswyk, D. van Lente and H. Marland. The original text has been shortened by about one fifth, passages which did not contribute directly to the argument being omitted. These omissions are indicated in each case by the insertion of '...'. Permission to publish the translation was kindly granted by the publishers of the original Dutch text and by a representative of the Forbes family.

Forbes' chair was supported by the Allard Pierson Foundation, which to this day funds historical research at the University of Amsterdam through the endowment of chairs. In 1960 Forbes became extraordinary professor, taking up a chair supported directly by the university. Forbes was appointed to teach the history of the applied sciences and technology, although he was not a historian by training, but a professional engineer holding a chemical engineering degree from Delft Polytechnic. When Forbes was first appointed at the university he had published a small number of papers on the history of technology, but the work for which he is best remembered, his book *Man the Maker* (1952) and the nine slim volumes of his *Studies in Ancient Technology* (1964-1972), had not appeared. The choice of Forbes for the professorship revealed a shrewd insight into academic promise on the part of the appointment committee. In the event it turned out to be fully justified.

As a professional engineer he had been employed by the Shell Oil Company, as had his father. Employment by a multinational company often implied, as it still does today, being stationed far away from the country of one's birth. It gives rise to mixed marriages and children who grow up to be international citizens, as in Forbes' case. Forbes senior was of Scottish descent, but had married a Dutch

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woman. Young Forbes attended the Public School at Shanghai International Settlement until 1912; hereafter he went to school in the Netherlands. As the country remained neutral during the First World War, he could continue immediately with his studies at Delft Polytechnic after completing high school in 1917.

Forbes could express himself equally well in either Dutch or English, which stemmed partly from his background and early education. But this ability is not fully explained by these circumstances, and he must also have been endowed with an aptitude for languages. Similarly, one may perhaps speculate that the germ of his passion for the history of technology nucleated during his early years, when he witnessed the confrontation between Western and Chinese cultures and technologies, but, in addition, he must have possessed a turn of mind which later enabled him to see the unique aspects of the process, which most people in the same situation would never have become aware of.

His interest in ancient technology was stimulated by his professional work as a chemical engineer on bituminous products, particularly their application, which could be traced far back into the history of Mesopotamia. This study must have initiated a chain reaction which led him to investigate other aspects of ancient Mesopotamian technology. We find the reports on the results of his findings in the volumes of *Studies in Ancient Technology*, some of which are still in print. Although these studies are inevitably somewhat dated, they remain excellent introductory texts to the subject.

Man the Maker was an attempt to provide a synthesis of the history of science and technology. It caused something of a sensation when it appeared in 1950, and, more than any other of his works, it established Forbes' authority as a historian. A somewhat amusing manifestation of the respect Forbes commanded took place in 1959 when the well-known classical historian Finley launched an attack on the history, or rather historians, of technology, on the occasion of the appearance of the second volume of Singer's work *A History of Technology*. Finley carefully exempted Forbes from his broadsides, although Forbes had contributed to Singer's work.

It is worth lingering with this episode, because it illustrates Forbes' significance for the development of the history of technology as a historical discipline. It is clear that Finley had been shocked by some of the contributions to Singer's book which displayed only a superficial acquaintance with social and economic history, and an apparent blindness to even very significant aspects of history. At the same time, the authors displayed a pedantic concern for exact dates. In 1959 Finley vented his scorn for these essays, and for the laxity of the editors who had failed to remedy the book's shortcomings, in no uncertain terms in the *Economic History Review*. Finley probably exempted Forbes from his harsh overall criticism because his book *Man the Maker* testified to Forbes' awareness of the socio-economic context of technological development. Looking carefully, however, one cannot fail to observe that Finley's criticisms did also bear directly on Forbes' contribution, without him being named. These errors were quietly corrected in the second edition of Singer when it appeared shortly afterwards.

It seems that once Forbes was launched on his track as a historian of technology he was well and truly hooked. It is as if an inner demon prodded him to produce one work after another, and also to further the cause of the history of science and technology as an accepted scholarly discipline through every means at his disposal. Major works from this period are the first three volumes on the life and work of the 18th-century Dutch physicist Martinus van Marum, the volume he contributed to the definitive edition of the work of the Flemish-Dutch engineer Simon Stevin, and the remarkable work *Overwinning door gehoorzaamheid* (translated as *The history of science and technology* (Harmondsworth, 1963)) which was written in collaboration with E.J. Dijksterhuis. In addition, he was active in organizing a large number of museum exhibitions, and from 1950 to 1955 he served as president of the 'Genootschap voor Geschiedenis der Geneeskunde, Wiskunde en Natuurwetenschappen'. In addition to all these activities, he continued to publish detailed studies on the history of engineering in a wide range of periodicals.

Forbes' significance as a historian of technology, however, probably should not be sought in these studies *per se*, but rather in his sensible and undogmatic approach to the subject. Today there seems nothing very remarkable about Forbes' stance, but at the time the 'history of technology' appears to have been regarded amongst engineers interested in the history of their profession as being equivalent to the sum total of separate developments of technologies. Characteristic of this 'internalist' view were encyclopedic works, such as those of Feldhaus or Neuburger, arranged according to technological subject. It was to Forbes' credit that he could contribute excellent antiquarian specialist articles to such *Sammelwerke*, and, at the same time, quietly and consistently pursue what he correctly regarded as history, that is, the history of the development of technology and society in close mutual interaction. It was this, more than anything else, which must be regarded as his most important contribution, at least so it seems to this commentator.

Even so, we cannot entirely overlook Forbes' shortcomings. His style of writing is flat, not always wholly transparent, and sometimes overly didactic. When he occasionally resorts to metaphor, it is always one so worn that one regrets that he did so. And, in spite of his industry and wide-ranging knowledge, he tended to accept the results of others rather too uncritically.

But his exemplary quiet defence of the history of technology as a historical discipline more than compensates for these deficiencies. If Finley rightly regarded the endeavours of his contemporaries in this field, with only a touch of exaggeration, as a disastrously blind and narrow-minded archaeology or antiquarianism rather than history, his recommendations to remedy the situation contained the germ for a disaster of a different variety. He maintained that the

history of technology was simply part of economic history, in which there was a modest place for good technological antiquarianism.
At first sight this proposal may not seem all that catastrophic, but its potential for becoming so is clear when we examine the examples which Finley provided when advocating his views on 'good' technological antiquarianism and archaeology. For instance, he regarded the work of Lefebvre des Noëttes as a model of its kind. Thanks to the work of Alison Burford, Mary A. Littauer and Jean Spruytte, we now know that the famous point of the self-strangling horse harness of antiquity, for which des Noëttes is mainly remembered, was largely based on incredibly superficial trials which were never adequately reported. Yet it was presented with such panache that most non-technical historians readily accepted it, although the conclusions were quite untenable.

In 1974 Finley provided another example of his lack of discrimination in this field when he returned to the attack, writing,

> I wrote a harsh review of vol. 2 [of Singer's book] ..., and I have no reason to retreat in any way. Indeed, my objections are strengthened by the pernicious influence this work continues to exercise; the more recent *Technology in the Ancient World* (London 1970), a popular introduction by an acknowledged expert, H. Hodges, for which the 'two main sources' are the Singer volume and the late R.J. Forbes' multi-volume *Studies in Ancient Technology* ..., reveals little interest in non-archaeological evidence, and, it appears from the text, little acquaintance. Forbes, I hasten to add, did not belong to this school of thought.

We would now comment that Hodges' popular account was definitely not representative of ongoing research in the history of technology.

Finley's infelicitous examples make it painfully clear that in order to discriminate between 'good' and 'bad' in this field one must possess at least some expert knowledge of the technical aspects of the history of technology. This is something which a classical or economic historian generally lacks, but which Finley apparently thought one could do without. Subjugating the history of technology to economic history would have institutionalized this lack of discrimination. It would have also implied an anomaly, because while no-one would seriously defend the notion that economic history could be written without knowledge of economics, or social history without a knowledge of modern sociology, it must be concluded that, similarly, technological history cannot be written without a knowledge of technology. That Finley's recommendation was never acted upon is probably in large measure due to Forbes' work.

Forbes carefully fitted the presentation of his findings with the ideas current amongst social and economic historians of his day, which no doubt contributed to their ready acceptance of his work. The reverse side of the coin is that his conclusions have not stood the test of time any better than their work, which in some respects now appears quite dated. This is particularly true with regard to the emphasis which was placed on the nefarious influence of the institution of slavery on technological progress.

It is clear from studies made during the last few decades that the conventional picture of the stagnation of technological development in Greek and Roman Antiquity was based on both the relative paucity of written sources and, with respect to archaeology, the quirks of site sampling and a lack of technical means or interest. The truth of the latter is particularly well illustrated by the case of the so-called Antikythera mechanism, a calendrical analogue computer which was probably made in Rhodes around 80 BC. It was recovered as part of a cargo of art treasures from an ancient wreck off the northern shore of the Isle of Antikythera between November 1900 and September 1901. Parts of the bronze calendrical gear mechanism were visible on the surfaces of lumps of calcareous accretion, but it was evident that it would be impossible to remove the thin and corroded gears from these lumps without totally destroying them.

Tenacious investigation of these remains, in particular by the late Derek de Solla Price, established the nature of the find. Between 1951 and 1971 he studied the mechanism by scrutinizing the exterior of the calcareous lumps, but it appeared that it would be impossible to arrive at a credible interpretation of the remains, as simply too little was visible. In 1971, a breakthrough was made in the form of gamma radiography carried out by the Greek Atomic Energy Commission, which enabled the lumps to be carefully examined. Thus it became possible to determine the number of teeth of nearly all of the 37 gears in the entire mechanism. It turned out that its principal function had been to predict lunations at any given date.

The significance of the find, and of its reconstruction, was formulated in 1974 by Price:

> Perhaps the most spectacular aspect of the mechanism is that it incorporates the very sophisticated device of a differential gear assembly for taking the difference between rotations, and one must now suppose that such complex gearing is more typical of the level of Greco-Roman mechanical proficiency than has been thought on the basis of merely textual evidence. Thus, this singular artifact, the oldest existing relic of scientific technology, and the only complicated mechanical device we have from antiquity quite changes our ideas about the Greeks and makes visible a more continuous historical evolution of one of the most important main lines that lead to our modern civilization.

It may be added that presumably the same result could have been obtained much earlier using X-ray radiography, but that at the time interest in the find was apparently not sufficient to overcome the practical obstacles in the way of such investigation. In retrospect these would have been entirely surmountable.

Another commonly held opinion in need of revision was that the ancients used no other sources of mechanical energy than animals or humans. The water-mill described by Vitruvius used to be regarded as an exceptional instance of 'high tech'. Although the grain mills of Barbégal – two parallel series of eight mills in succession, which bridged a difference in water level of 18.6 metres – had been uncovered in their entirety and reconstructed by Fernand Benoît as early as 1940, they were largely disregarded. It has been calculated that they were the driving elements of a flour mill which could supply the entire needs of the nearby Roman town of Arles. Although it is true that this factory is the only one of its kind from this period to be recovered so far, the water-mill was by no means an isolated phenomenon in the Roman Empire, as is evident from the work of Ørjan Wikander. His doctoral thesis of 1980, based on both literary and archaeological sources, provides evidence on several scores of Roman water-mills all over Europe. Continuing investigation is resulting in constant additions to the list of these mills, further contradicting the older concept of slave-holding antiquity without inanimate prime movers.

Finally, it would seem that we think somewhat differently now about the catastrophic separation between science as a 'mode of knowledge' and as a 'way to do something', as it was perceived by Forbes. It is a theme which is still very much alive, for example, in the ongoing debate on the relationship between science and technology during the 'second industrial revolution'. It is a vast subject, and it is only possible here to make few remarks. No doubt Forbes was right in stating that the "break was fatal for the development of classical science, which without experiment and without nourishment by craft experience turned into idle speculation on the basis of axioms and strictly logical reasoning devoid of all living roots." On the other hand, one may wonder whether in fact the statement does not imply indulgence in a variation of the futile game of history-as-it-might-have-been. Was it physically possible to set up specially designed experiments in Antiquity, as Forbes seemed to think? To this commentator it seems doubtful; instead, we should think of intelligent observations of nature as being the most that could be attained. We note in passing that the French word 'expérience', which encompasses both 'experience' and 'experiment', suggests that for a long time there was no sharp distinction between the two.

Moreover, to regard the exchange between science and craftsmanship in Antiquity as going only from the bottom to the top, something Forbes insisted on, misses an important point. For example, Archimedes' applications of the screwline, a geometrical concept, no doubt greatly benefitted early technology and craftsmanship. Applied geometry gave Hellenistic technology a character which is unlike that of any other pre-modern technology.

Nevertheless, although we might answer them somewhat differently now, Forbes did ask the right questions, which is no mean accomplishment. If we now turn to his inaugural address of 1947, when both his development as a historian of science and technology and that of the discipline itself were mostly still around the corner, we hear in our 'mind's ear' an earnest voice speaking an unpoetic but honest and authentic language, implicitly pleading the cause of the history of technology as a viable historical discipline in its own right.

Science and the crafts in the ancient Near East, by R.J. Forbes

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Today we wish to cast light on a greatly neglected problem, that of pre-classical science. Too often it has been written – and too often classical scholars have repeated – that science began only with the Greeks. Only a few months ago Randall could write: "There was knowledge before the Greeks, but no science. Science as we know it was a Greek creation."[1] But this narrow position can hardly be maintained. Amongst classical scholars a conviction has gradually taken shape that intellectual contacts between the West (the Greeks) and the East (the Near East in particular) were much more intimate than has previously been imagined. Even though their worlds of thought were poles apart, the two were connected by many invisible threads. The same is true of Greek science and its older, pre-classical counterpart.

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Adopting Crowther's definition of science as "the system of behaviour by which man acquires mastery of his environment," we can say that, already in the earliest times, man made a number of scientific observations on which pre-classical science was founded. We must pass over Harrison's penetrating analysis of invention and discovery amongst primitive and early peoples.[2] We will only note that these inventions and discoveries, made on the basis of very early observations, provided the foundation of our present-day science. To distinguish edible animals and plants; to discover how to catch and gather these; to recognize the seasons and times and how these become a part of one's mode of life – all this already belongs to the Palaeolithic era. Here lies the basis of what we now call zoology, botany, astronomy, climatology, and so on. The mastery and the making of fire, and the creation of an ever more varied set of tools made possible the flowering of chemistry and physics.

A novel flow of techniques was initiated during the Neolithic era: making ceramics; weaving and spinning; building houses and working in wood; grinding and polishing stone. The blossoming of agriculture led to techniques for ploughing and digging, for harvesting and sowing, for grinding and baking. The chemistry of pottery; the physics of spinning; the mechanics of the loom; the botany of flax and wool and cotton were slowly brought together as pebbles in the mosaic of practical experience.

Civilization in those times was very much a local affair, and in every culture the locally acquired sum of experience was increasing. But local traditions were

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[1] H.J. Randall, *These Creative Centuries* (London, 1945), pp. 29-42.

[2] H.S. Harrison, "Analysis and Factors of Invention," *Man* 27, 1927, pp. 43-47.

disseminated too, and, as Childe rightly noted, the subsequent history of the sciences is primarily the history of the diffusion of useful ideas from the local, tribal environment where they had been conceived and developed, towards foreign places where they were stripped of elements and forms of local tradition, and where they were absorbed if considered valuable after a comparison with one's own techniques. Even the human mind then was not limited to the development of ideas which could be given shape in the form of useful tools and weapons with which the natural environment could be mastered. A store of germinating scientific thoughts and experiences was also formed as part of the integral view of life of that epoch, which was no doubt intimately connected with traditions, beliefs and ideals in the domains of religion, society and economic life. There was no separation between science, religion or any other facet of the life of the mind. In assessing pre-classical science one does well to bear this in mind.[3] One may regret that the first surviving written technical documents of which we possess knowledge are suffused with ritual and magic, but that is completely shaped by the progress of history.

The cumulation of experience and observation increased rapidly. Technical operations – particularly in metallurgy – became more complicated than those of the hunter and the farmer. We observe here for the first time the rise of a 'profession', held by a 'professional', a craftsman, for whom it forms a full-time occupation. It was only the surplus production of agricultural society which enabled him to perform his work. The flourishing of craftsmanship as exemplified by the smith involved a social revolution. A nexus of metallurgical traditions, woven in the fabric of religious and magical concepts, was disseminated all over the world. The smith's ritual and technical operations were still so strongly related that one can hardly distinguish between them; they flowed together. Hence the strong conservatism of metallurgy one encounters when it was diffused over the world at that time, which, incidentally, no doubt also influenced the diffusion of the smiths themselves. The craft guild acquired a position beside the tribe or clan. Smiths formed the first craft guild, soon followed by potters with their newly invented potter's wheel, etc., and by many other groups of craftsmen.

When, shortly before the historical period, the three city-centred civilizations of the great river valleys arose in the Near East, one observes a complex of social layers in them, and many groups of craftsmen which we can regard as approximating craft guilds. The invention and diffusion of script brings us much closer to their world, since material remains cease to yield the sole key to the past – inscriptions, tablets, and papyri enable us to form a picture of thought in those times. The cuneiform tablets from Mesopotamia date from the Uruk period, and

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[3]W.B. Kristensen, "Antieke wetenschap," *Mededeelingen Koninklijke Nederlandsche Akademie van Wetenschappen, afd. Letteren* N.S. 3, 1940, no. 8; H.R. Frankfort e.a., *The Intellectual Adventure of Ancient Man* (Chicago, 1947).

are probably the oldest written documents. Speiser assumes that this script goes back to the seal cylinder, that typical house mark of property rights, which managed to intrude from Mesopotamia even into Egypt, although there the stamp seal was later the more customary form.[4] Script is an invention marked by a social order which respected personal property, and script has since been the most typical personal mode of expression for human thought. We must be aware, though, of the fact that script did not immediately become the means to codify all tradition. Gandz rightly called our attention to the value attached in earlier periods to oral tradition and to the tenacity with which religious laws and traditions in particular, were passed on orally to later generations and not in written form.[5] It is a striking fact that, contrary to what one would expect, oral tradition is very faithful to the text, even though this also follows from the nature of what was passed on. Tradition is rendered in fully written form at a relatively late date, and only since then is it accessible to us in its entirety. These facts should remind us to pass judgment only with the utmost circumspection upon the summary remains of scientific writings from previous centuries.

As we saw, pre-classical science was based in the first place upon the experiences and observations of the crafts – of the smith, the potter, the glassblower, but also, in an even more distant past, upon those of the cook, the hunter, the farmer and the shepherd. Beside this, the religious conceptions of the time played an preponderant role; these were indissolubly linked to all the expressions contained in the first writings. We meet here a phenomenon which has been characterized by Sarton as "The Unity and Diversity of the Mediterranean World."[6] The large measure of spiritual unity that arose despite local diversity in this area, was in part due to special geographical features. Strabo (I.1.16) already mentioned that life there is ambiguous in every respect, "because in a certain sense we are amphibious, not belonging more to the land than to the sea." The Mediterranean served as a catchment basin for commodities and thoughts, which were redistributed along the length and breadth of its coasts since time immemorial. This well-known phenomenon reached its culmination under the Roman Empire. We see how during the classical period of civilization its centre first moved to the West, then back to the East. It is this which induced Cumont to observe: "The East was superior to the West by the extent and precision of its technical knowledge as well as by its inventive genius and the expertise of its craftsmen."

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[4]E.A. Speiser, "Ancient Mesopotamia and the Beginnings of Science," *Nature* 146, 1940, pp. 705-708.

[5]S. Gandz, "The Dawn of Literature, Prolegomena to a History of Unwritten Literature," *Osiris* 7, 1939, pp. 261-522.

[6]G. Sarton, "The Unity and Diversity of the Mediterranean World," *Osiris* 2, 1936, pp. 406-463.

The Near East had acquired this technical advantage in pre-classical times, because it also formed a strong unity, although unlike its classical counterpart to which it was linked so closely it was not amphibious. This earlier unity was the result of the rise of the three great civilizations out of the older agricultural civilization of protohistorical times. They had preserved its powerful spiritual elements which kept them bound together, despite different and always diverging growth. These very foundations of the pre-classical conception of the world mark the world of thought in which experiences and observations of the earliest craftsmen were adopted. Even if we do not always read it in the texts, archaeology teaches us the same, viz. how quickly and how far these experiences and inventions were spread across the whole area, and even far outside it to regions in Europe and Asia where life was still lived according to a prehistorical mode.

It is undoubtedly true that the study of the techniques and materials then in use is still in its infancy and should be pursued energetically. ... The more deeply we investigate available material, looking in particular at the connections out of which it arose and developed, the more respect we gain for the state of knowledge at the time and the more profound our understanding becomes of the conditions under which it all originated.

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In Egypt, much knowledge was apparently transmitted orally from generation to generation. This is made clear by the reports of such Greek travellers in Egypt as Thales, Herodotus, and so on. Egyptian mathematics, so far as we know, was typically directed towards the practicalities of everyday life.[7] As in Mesopotamia, we encounter here a search for practical rules and prescriptions or solutions, rather than a search for the theoretical background. Nowadays, too much emphasis is placed on what remained unknown. But if one considers, for example, Egyptian medicine, one observes the first surgical experiments; elaborate pharmaceutical recipes; the application of bandages and splints, and also the earliest, extensive nomenclature for medicine and anatomy. Truly a considerable groundwork for Greek medicine to build upon further.

But we must be aware that this science was linked very closely to the pre-classical world of thought, and that there was no possibility for a contradiction between the sciences and religion such as appears often to exist nowadays.

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For want of a better term I have recently labelled the conception of the world in the Near East as 'magical' as opposed to the 'logical' one of the Greeks.[8] If we do not attach too profound a meaning to these terms, they allow us to note how

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[7]See also W. Flinders Petrie, *Wisdom of the Egyptians* (London, 1940).

[8]R.J. Forbes, *Wetenschap en techniek in de Oudheid* (Den Haag, 1944).

magical science arranged its carefully observed facts in the framework of a world order posited a priori. Thus Kristensen argued convincingly that the Egyptian was concerned with the place of phenomena in the divine world order, not with the logical links between them. The latter has value only if phenomena are taken as discrete, and are then interconnected. If the unity of things is stressed before all else, discreteness, independence, and the relations to other things are much less important. In such a case the place allotted to a component in the whole equally determines mutual relations. To 'give a name' to things was very important in pre-classical thought because doing so implied knowledge. This was the 'Net of the World' into which all discrete units merged. Causal links were irrelevant there.

It appears that the old languages had no word for knowledge in the sense of intellectual penetration. Old-Egyptian *rh* and also *si3*, or Akkadian *idu*, all seem to represent rather 'making the acquaintance of', 'observation', that is to say, a sensory scanning of things in order to place them, upon recognition, in the divine order of the world. We do not appear to find here a 'divine curiosity into the essence of things'. A deeper investigation of these and similar terms is urgently required to give us more certainty.

We are not compelled to consider this attitude as a reason for disapproval of ancient science. The aim of science must be to collect and to systematize facts and experiences, so as to enable the community to use these with success in governing conditions in the surrounding world. The more successful one is in making nature serviceable, the more proof one holds of the 'truth' of the laws and connections one believes to have discovered. The curious, pre-classical combination of, on the one hand, an extreme practical attitude and, on the other, a religious-philosophical mode of dealing with the facts, found its expression in language and in written documents.

Script is perhaps the most important invention of humankind. It is certainly the most proper means for contact with the past and its world of thought. As the early urban civilizations gradually spread we see script being used more and more for writing down craft experience. Documents teach us what was known then of mathematics, arithmetic, geometry, astronomy, medicine, theology, and so on. The act of writing down and of spreading facts makes tradition impersonal, as opposed to oral tradition transmitted by the master. But wider circles come into contact with the facts, which indicate certain directions in natural processes – sometimes these are even used to predict what will happen in nature. Beside real sciences, we also see the rise of pseudo-sciences, such as astrology, albeit at a later stage.

Script had other consequences too. A group mastering this difficult art arose; these men were literally called 'scribes'. In a society where religion penetrated the whole of life to such a large extent, they could only be priests. After all, in these times, as in the early Middle Ages, priests performed services which were later entrusted to laymen. Was not one's entry into priesthood often the only possible way of breaking through the crushing bonds of a rigid class division, and did not the social order often entrust numerous administrative and technical tasks to priests? Of course there was a risk involved. Script had revolutionized the mode of collecting scientific knowledge and the transmission of experience – a new kind of science was being born. The fact that the command of script started not with the craftsman but with the priesthood, makes it comprehensible to us that a possibility existed for the construction of a compound of 'higher learning' and science, which was no longer in direct contact with the fountainhead of facts and experiences – the crafts.

The divergence between science and the crafts, insofar as the former was effected by it, entailed the risk of written science becoming just as conservative as traditional craftsmanship. In classical texts an appeal to the 'wisdom of the ancients' often takes the place of direct observation. On the other hand, as today, the crafts were strongly bound to tradition, and true written recipes and descriptions of a craft are not to be found until later times. The existence of organizational links between craftsmen and priestly scribes could not but benefit young science. In pre-classical times the separation between science and the crafts was certainly less strict and less sterile than, for example, in the fifteenth or the sixteenth centuries, or even in classical times.

If we recall the great significance attached to the 'name' in the earliest conceptions of the world, we can understand what place Sumerian lists of names must have occupied in pre-classical science. It is very well possible, and indeed quite certain, that these played a large part in education, just as ideograms still do today in China. Education by means of ideograms explained orally is certainly just as concrete and imitative as education in the workshop of the master! The arrangement of derived words and of related concepts ('related', that is, in the opinion of the times), no less than the very early usage of script for stock-taking and book-keeping, led to more strictly systematic thought than would have ensued from nothing but the recording of religious and magical facts.

The strict arrangement of things in name lists, in accordance with putative connections between them, made it easy to situate things in the Net of the World. But there was no question of a tendency amongst scribes to investigate or critically discuss the course of developments. They confined themselves to the systematization of experiences of earlier generations. They did not think of experimentally verifying the phenomena of the magical world. Everything in their documents is penetrated by the magical view of life. When Akkadian texts give an expression for 'working out a computation', they say literally 'to carry out a ritual'. Early Sumerian lists of words were later provided with Akkadian equivalents and still later also with philological glosses, which means that in Mesopotamia, earlier than in Egypt, the framework for comparative linguistics was created. The early Sumerian written signs more or less take the place of mathematical or physical symbols, or rather of chemical terms for radicals and groups – that is if they are arranged in lists of names. The survival of such orderings in Akkadian-Sumerian 'dictionaries' contributed its share to the transmission of the new scientific mentality to the new Semitic masters of Mesopotamia. The competition of a variety of temple schools in neo-Babylonian times led to an intense intellectual life and contributed to the further development of ancient science.

This curious mixture of a magical conception of the world with a practical course of development in technical matters, made Meissner lament that the purpose of the Oriental religions was purely practical and materialistic, and that in Mesopotamia no science was known in the sense which we attach to the word.[9] But he is thinking here wholly from our modern stance. In Akkadian the word mudu was being used for 'scholar', which was applied equally to an experienced craftsman. We know of noblemen who took part in the practical application of science. On the other hand, the cult was labelled dullu, which literally meant 'labour', namely for the gods.

Many documents describing technological practice are still unclear to us. Often one is struck by symbolic terms which remind us of alchemical pseudonyms, and a comparative study of these matters would no doubt yield surprising results. Campbell Thompson, whom we were unfortunate enough to lose in the war, opened up for us a treasury of knowledge about practical chemistry and geology.[10] His research led him to the conclusion that the limits of performance in ancient craftsmanship should not be too narrowly projected. The few remnants show that often 'professional language' or pseudonyms were used in order to hide carefully the secrets of the guild brethren. "Let him who knows teach him who knows; but let him who does not know not teach him who does not know!" it is put in one text. Many pseudonyms are based on puns, for example, eru: eagle is used for eru: copper. But one must always be aware of the ultimate aim, even though the texts do not always make it apparent. Campbell Thompson pointed to the Assyrian medicinal texts, where we encounter the same phenomenon. As he expresses it: "Mystery, hocuspocus and solemnity of the Guild of Assyrian Medicine are nothing more than a due interpretation of an Assyrian bed-side manner." But there exist hundreds of recipes and texts without the slightest indication of a magical nature, which begin with a diagnosis followed by a purely scientific treatment. We read the same in the Egyptian papyri in this field. He rightly ascribes the advanced stage of chemical knowledge of the Assyrians to the fact that so many materials were subjected to the action of fire – which Pliny (*Nat. Hist.* 36, p. 300) states was

[9]Br. Meissner, *Babylonien und Assyrien* vol. 2 (Heidelberg, 1925).

[10]G.C. Cameron, "The Babylonian Scientist and his Hebrew Colleague," *Biblical Archaeologist* 7, 1944, pp. 21-29, 32-40; R. Campbell Thompson, *Dictionary of Assyrian Chemistry and Geology* (Oxford, 1936); O. Neugebauer, "Exact Science in Antiquity," *Nature* 146, 1940, p. 625.

necessary for almost every operation in ancient technology. The texts show that the attendant phenomena were being observed sharply and accurately.

Beside the mudu Mesopotamia also knew the ummanu. Sidney Smith links him to the 'expert professional' in Proverbs, and to the 'expert craftsman' in Canticles VII.1.[11] Other than in the Septuagint, though, this should not be translated by 'technites', because the term seems always to represent a special kind of craftsmanship. Apparently Bezold confused the older Akkadian term ummanu with ummanu, ummantu, soldiers or army. Such an expression as mar ummani points rather to a particular group of scribes. In the *Gilgamesh* epic (tablet II, col. IV, pp. 29-38) they are mentioned as counsellors on the nature and weight of weapons. The 'Ummanu-officials' occur both in Babylonia and in Assyria. In the former country they are often princely persons, who act as a kind of treasurer; in the latter they appear to have some special executive task in specific activities.

They are also known to us from much older commercial texts in Asia Minor, and Smith applies further philological considerations to explain that their title must be translated as 'those who give instructions'. Hence, they should be seen as foremen or overseers of technical works, alongside the mudu or professional scholar. It is not surprising that in so ancient an environment such technical supervision was organized by the state, since we know that certain valuable resources, such as ores or pig iron, were often purchased by the state, and were subsequently distributed from central stores to be processed. It is quite understandable that this happened under official supervision. The texts discussed by Smith do not as yet make it clear whether we must also attribute priestly authority to the personnel charged with direction and supervision, but this question certainly merits further examination.

For Egypt we know a good deal less about such an organizational link between what is sometimes called 'temple science' and the technical professions. We do, however, have various documents concerning a 'House of Life', and even the remains of such buildings. We must conclude from such data that we are dealing here with some kind of Academy of Sciences, with the primary task of protecting the life of the gods and kings by all means available to the magical world, and of assisting the king in word and deed. Within the competence of the 'Scribes of the House of Life' fell theology, the reading of dreams and magic, but also medicine, handicrafts, architecture, the arts, mathematics and astronomy. The members of this academy held various priestly ranks. ... So it appears that in early times a distinction was being made between the scholar and the craftsman, whereas later the two merged. It remains to be further investigated whether this was a sign of a looser sense of language, or whether it had some deeper significance.

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[11] S. Smith, "An Inscription from the Temple of Sin at Huraidha in the Hadramaut," *Bulletin of the School of Oriental and African Studies* 11, 1943/46, p. 3.

Childe's fear of a separation of 'higher learning' and professional knowledge does not seem justified to us. Some cases are known of Egyptian scholars trying out water clocks. It is true that experiment, which is so typical of our Western science, surfaces with the Greeks too, albeit occasionally, and occurred only sporadically in Antiquity. But it is there, and we do not yet know what a further examination of the texts may bring us. It is clear, however, that science did not stand aloof from the crafts when technical experience was collected and developed, and that there was interaction, though not in such a form as the superficial imagination would suggest. There was certainly direct contact between the crafts and the world of scholars. We do not know whether any creative influence was exerted from top to bottom, but the reverse is more than probable.

It is clear, for example, that the surveyors of ancient Egypt had an important influence upon the development of the arithmetical and geometrical problems that were being investigated. Even though no continuous range of astronomical documents from all periods is available to us, Chatley did make it clear that the principal phenomena were already known in early times.[12] Lists of Decans and pictures of the zodiac go back at least to the New Kingdom, when they were given their final shape. The systematic clarity of Egyptian medicine already shines forth from the oldest documents, unmistakably suggesting a well-considered assimilation of practical experience.

This exceedingly vague picture of pre-classical science may urge us to devote more attention to these topics when we study the ancient Near East, because after all they formed a very interesting and integral part of it. Whereas classical technology more or less followed straight on from its pre-classical counterpart, since it continued to find its principal inspiration in the East, classical science – how could it be otherwise – displayed a character of its own. Let us look for a moment at science and technology in the classical world, thus to put into clearer relief the relationship between classical and pre-classical.

Much has already been written about 'le miracle grec' without giving a definitive explanation, nor does such an explanation exist.[13] The sudden flourishing of Ionian natural philosophy, and its being grafted on to the Greek mainland, had many causes, not all of which we can now fathom. The Ionian cities were situated at the border of two worlds, of which we should imagine the Greek as being more colourful and more 'Eastern' than we are customarily ready to concede. The bonds with the East were very strong, but this does not detract from the originality of Greek civilization, which assimilated these elements in its own way. Commercial contacts with the East; the influence of recently introduced coinage, and many other

[12]H. Chatley, "Notes on Ancient Egyptian Astronomy," *Observatory* 62, 1939, p. 100.

[13]R. de Sausssure, *Le miracle grec, étude psychoanalytique sur la civilisation hellénique* (Paris, 1939).

factors created problems in the Ionian world which required solutions. If, besides this, we consider Greek freedom from theological dogma, the love of abstract thought, the nature of public life, then we realize how many factors contributed to the Ionian philosophy of nature.

However this may be, the earliest Ionian thinkers were physiologoi, that is, they searched for 'the natural growth of things'.[14] Their search should not be confused with evolutionary theories; they were concerned with 'becoming' in a very different sense. Diodorus, amongst others, passed on to us from Hippocratic sources certain thoughts about the history of the earth and the generations of living beings produced by the earth. But these thoughts are very far removed from the evolutionary teachings of Darwin, Lamarck and Spencer. The Ionian thinkers were typically oriented towards technology, seeking to grasp the motions of the heavenly bodies and the principal events in nature by means of concepts borrowed from the crafts, with which, as merchants and traders, they were familiar from their day-to-day activities. Here one is reminded of how little on Thales' life has been passed on to us. Time and again, they fell back upon daily experience in their search for the original principle, the arche which was taken to underlie all phenomena of nature. The solution to the question, of what things ultimately and truly are, was to be found in the material nature, or form of this original principle. To take this higher, lifegiving principle as a primary factor is really something quite different from the modern way of observing the world of the senses, which seeks to turn that world into an interconnected ordered whole, measurable in all its parts.

Stimulation of thought by these Ionian thinkers, however, continued to foster a further rationalization of the conception of nature. Therefore, we already meet the onset of our modern conception of nature in the next generations, those of Empedocles, Anaxagoras, and Democritus. The best writings of the Hippocratic corpus belong here as well. Time and again, these fell back on observation of daily life, and an 'ideal' rudimentary principle comes less and less to the fore. Ever more practical experience was assembled to support the theory and to give a rational explanation of things, even though the 'One and Many', which was also reflected in the fragmentation of everyday political and social life, did not cease to occupy thought.

The limited utilization of experimentation in these theories was still typical.[15] The argument was often based on erroneous observation of some rare experiments,

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[14]See for instance F.M. Cornford, "Was the Ionian Philosophy Scientific," *Journal of Hellenic Studies* 62, 1942, pp. 1-7; H. Gompertz, "Problems and Methods of Early Greek Science," *Journal of the History of Ideas* 4, 1943, pp. 161-176; B.A. van Groningen, "De Griekse zin voor wetenschap," *De Gids* 1936, pp. 174-186; E.J. Dijksterhuis, "Maatschappelijke invloeden in de Grieksche natuurwetenschap," *Hermeneus* 18, 1946, pp. 23-29.

[15]K.C. Bailey, "Progress by Trial and Error," *Irish Journal of Medical Science*, september 1945; E. Färber, "Coppernicanische Umkehrungen in der Geschichte der Chemie," *Osiris* 5, 1938, pp. 479-498.

and a little more experimentation would have revealed this. Disputes consisted of tracking down mistakes in the argumentation, and were rarely settled by setting up a new array of checks. Only in medicine, with its strongly practical orientation, do we see an ever more extensive resort to experiments, coupled to an equally increasing elimination of divine and magical causes. The conception of illness as a natural phenomenon gained ground, the material causes of which can be taken away by careful observation of phenomena and subsequent intervention by the physician. In the other sciences, convictions concerning the existence of natural laws of cause and effect were still very weak; the element of 'fate' or 'divine intervention' still played a large role. There was no such concept as a mechanical unfolding of the course of nature according to fixed natural laws. A 'mechanistic' conception of nature could not fail to be absent in a world in which the mechanical still played so minor a role, and vice versa. In the Ionian school, the idea still predominated that science is a mode of contemplating things in order to arrive at a correct understanding of how to handle these in order to attain one's declared goals. The guiding idea here was 'at the bottom like at the top'. This is the reverse of what the alchemists propagated, the 'at the top like at the bottom', which would have been accepted in the pre-classical world. It would be interesting to examine when episteme lost the old meaning of 'art, skill', and acquired the novel one of 'science', as it certainly had acquired with Plato. The separation of craft and science certainly did not occur until Greek thought had passed beyond its culmination point.[16]

The change of course of classical science, from 'a way to do something' to 'a mode of knowledge' was due to the rise of Pythagoras and his school. In spite of all the progress produced in mathematics under their guidance, this doctrine was a step backwards to the pre-classical conception, and also marked the beginning of the fatal separation between science and craft. The Pythagorean 'number' differed only marginally from the Sumerian 'name'. In principle both put the essence of the process of nature above what is observable in everyday life. The universal truths stood as steadfast, eternal realities behind the Ionian world of the senses, which was attacked for the first time by Parmenides. With Plato's appreciation of an ideal geometry over and above its directly observed counterpart, sentence was passed upon the onset of a dynamical conception of nature which, in principle, was present in the Ionian school. Greek science became static like its pre-classical predecessor, albeit modified in accordance with the Greek character and devoid of theological elements. Plato despised those who 'put their ears above understanding'.

Aristotle was never quite able to cast off this abstract science, which moved

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[16]D.M. Balme, "Greek Science and Mechanism," *Classical Quarterly* 35, 1941, pp. 23-28; H.B. Torrey, "The Evolution of Mechanical Ideas in Ancient Greek Thought," *American Naturalist* 72, 1928, pp. 293-303; A. Aynard, "Hierarchie du travail et autarcie individuelle dans la Grèce archaique," *Revue d'histoire de la philosophie* 1943, pp. 124-146.

away from experiment more decisively than before, even though many of his works, in particular the later ones, testify to a purer notion. Perhaps this letting go of craft experience had social reasons. We are thinking here of statements by Xenophon (*Oeconomicus* IV, 203), who regarded all manual labour as dishonourable because it leaves the craftsman no leisure to discharge his civil obligations. This disparagement of manual labour, which was unknown in earlier times, continues to fill Greek thought. But the break was fatal for the development of classical science, which without experiment and without nourishment from craft experience, turned into idle speculation on the basis of axioms and strictly logical reasoning devoid of all living roots. Epicurus' warning that 'it is wrong to conflate natural philosophy with the making of laws' was cast to the wind. The contact between science and craft, which could have been mutually fertile, was severed until the end of the Middle Ages. The great tragedians, such as Aeschylus and Sophocles, might have sung the praises of the triumphs of human inventions and discoveries. But in the classical world science died a slow death, cut off as it was from all new matter for contemplation.

Various authors, such as Farrington, Torrey, Salant, and Cornford have made it clear that this 'aristocratic' move away from the crafts was intimately linked to the social consequences of the slave society of later antiquity. The death blow was administered to science when the Romans united the Mediterranean into an Empire. Rome had no interest in these matters. It cared more for the moral qualities needed to maintain the state and state power. The Roman treated science as an instrument for his political objectives. Science withered in a society which became ever more totalitarian, thus, as Farrington has argued persuasively, turning into an impediment to the free development of science.[17] The Roman was no friend of abstract thought, and the centre of gravity of science during his Empire was in the East. There, in Alexandria, and later in Byzantium, Antioch and other Hellenist cities too, science, under the influence of the Greek world, came once again into close contact with the craftsmanship flourishing in these regions. Stimulated by the generosity of interested princes, science passed through a brief period of late flowering, until here too the heavy hand of the Roman impeded further progress.

Manual labour fared differently in classical times, especially, once again, in the East. We really know much too little about the crafts in the Greek world during its early and mature flowering.[18] Up until now classical scholars have concentrated too much on intellectual life, and we urgently need a deeper study of Greek and Roman technology and its interactions with the intellectual life of the ancients. As

[17] B. Farrington, *Science and Politics in the Ancient World* (London, 1939).

[18] We have to wait and see what the book announced by Abel Rey, *l'Apogée de la science technique grecque* (= *La science dans l'antiquité* vol. 4) will bring.

Farrington rightly remarks, "there is no sense in longer continuing our wonder of the anticipation of modern ideas" – a fruitless and often very much distorted speculation. "The history of science should be really historical," so he rightly concludes. If at the time of Socrates sophia and techne met with equal appreciation this must have deeper roots, and archaeology teaches us that in a variety of domains Greek technological ability had without doubt reached a very high level.

Here we need not only think of bronze and earthenware appliances, which were also works of art. The thin walls of this earthenware and cast bronze testify to the great skill of the craftsman. In the East the art of the jeweller and the goldsmith, and also silken fabrics and glasswork, arouses our particular admiration. Fine instruments such as the clepsydra and the dioptra were known too, and many an ancient tool displays a finishing touch so pure that it cannot be improved upon without our modern lathe or machine. In the domain of specialization we need only think of the physician's set of instruments. Anyone who refers to the works of Blümner, or of any other author who has not confined his attention to what was 'new', will be impressed by the scope of the crafts in those times.

This is of course determined in large measure by economic factors. The ancient world, during the Empire in particular, formed a powerful unit, with the exchange of data and commodities, yet commerce in general was limited to the most important resources and products, and especially to luxury goods. There was still little trade in semi-finished articles. Apart from bulk products such as grain, olive oil and wine, maritime commerce had as yet little to offer to the masses, focused as it was upon a small circle of consumers. Most of what industry produced followed the laborious, costly overland routes, and did not move far away from the sources. Even though the 'Hauswirtschaft' stage propagated by Bücher does not apply to the Empire, and even though we do know of various specialized industries, which operated more or less like later manufacturies, free craftsmanship went on flourishing up until the late Empire. The slave as a 'living tool', as Aristotle literally called him, has been too much the focus of attention. It is doubtful that in industry the slave worked so cheaply and so well that he could displace the free craftsman. The facts seem to contradict this. The supremacy of slave labour applied only where simple labour, to be carried out by masses of people, governed the production process, for instance, in agriculture. A closer examination of classical craftsmanship will certainly find much support in economic data.

Ancient technology was also great in warfare. The fourth and also the third century BC must be mentioned with honour as the period of military technology. In the Roman period grandiose feats of hydraulic and road engineering in particular call our attention, as well as civil engineering. The products of the Roman engineers, whose usual material, concrete, was the only important invention of the West, displays strongly 'American' features. Here not the artful automata of the Hellenistic Alexandrines, but the large roads, bridges, vessels, harbours, canals and aqueducts arouse our admiration. The absence of the machine is striking. True, many and frequently large tools were applied – nor should one condescendingly pass by these achievements – yet all this was obtained chiefly through mass labour. Even the inventions themselves are not Roman in origin. The aqueduct was developed out of the ancient irrigation systems of the Near East; arch and bridge had been familiar there for a long time; the construction of harbours and tunnels was carried out on a large scale already in Hellenist times.

Here the disparagement manual labour suffered in Greek times, and the chasm between the crafts and a science now withered away, made themselves felt with a vengeance. For it was not only the slave, as a cheap tool, who furthered this development, but the absence of scientific investigation of the special role played by natural phenomena. After men such as Heron and Ktesibios, the mechanical development of craftsmanship would most certainly have been possible. But this was precisely the domain where the ancients did not progress. They merely toyed with the forces of steam and wind. Passive forces such as weight and pressure were put to service, followed by those of motion, gravity and heat. But the wind remained the enemy of the ancient engineer, and also of the ancient mariner, who continued to prefer rowing power to the typical sailing vessel. Winds in the Mediterranean are treacherous, and ancient man never tamed the wind. The windmill was an invention of the inhabitants of the Persian high plateau. True, Ktesibios used air pressure in his tormentum as a mechanical force, and Philon makes modest usage of it in his automata, but as a moving force it plays no role in ancient technology.

The exploitation of water power by means of the water wheel, perhaps influenced by the few continuously flowing rivers in Greece and Italy, underwent a similar fate. Paddle wheels and water wheels for drainage were moved by animal or human power and did not constitute substitutes for these. Unfavourable natural conditions alone, however, cannot explain this neglect in harnessing natural forces. Chapot rightly makes a distinction between tools which relieve human labour and those which replace it, which, therefore, may truly be called machines.[19] Ancient man paid almost exclusive attention to the former. He applied the principle of the lever in his tools, and made use of counterweights in drawing water. Such improvements offer relief, but certainly do not eliminate animal and human labour. The machine, which does precisely this, was known to ancient man only as a toy. We already indicated that the idea of a mechanistic process of nature – one driving force towards the machine – was absent in Antiquity. The disdain for manual

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[19]V. Chapot, "Sentiments des anciens sur le machinisme," *Revue de l'Egypte Ancienne* 1938, pp. 158-162; A. Rehm, "Zur Rolle der Technik in der griechisch-römischen Antike," *Archiv für Kulturgeschichte* 28, pp. 135-162; W. Salant, "Science and Society in Ancient Rome," *Scientific Monthly* 47, 1938, pp. 525-535.

labour and the large number of slaves sufficient for public works, offered little stimulus for a development in this direction. Science, which examined nature as part of a search for peace, happiness and wisdom, did not take the direction of a mastery of natural forces, and did not care for results which might make man richer and might yield greater material prosperity for everyone. Science did not acquire such a background until the work of Bacon. We leave here aside the ethics of such striving, but confine ourselves to noting why the machine did not enter Antiquity. It is clear that in Antiquity, the crafts also withstood mechanization, but this did not result in a serious clash as it did during the Industrial Revolution.

Salant rightly pointed out that the leading Roman circles cared little for science, whereas they might have provided the very driving force behind it, because they were in possession of the means of production. Only when agriculture, because of the slave trade, was in danger of losing income, did Varro, Cato and Columella call in science to improve production. In the end, state measures such as binding workers to the soil had to provide the solution. As the West became increasingly totalitarian, or attained quasi-aristocratic modes of administration, the interest in science vanished and the crafts withered.

Only in the East, where craftsmanship was sustained more strongly by a nourishing tradition, can one speak of further development. Here, as a late flowering of Alexandrian science, a new science, chemistry, arose out of a blend of elements from cookery, medicine and pharmacy, metallurgy and jewellery-making and from centuries-old 'experiments with fire'. Gradually this new science began to strive for its present-day objective – knowledge of the composition of substances. In other areas, too, such as mathematics, astronomy and medicine we still find original contributions in the East, which had a part in keeping alive the results of Greek science and ancient craftsmanship, until the Arabs picked up the torch, which they, after a number of centuries, in their turn passed back to the West.[20] Here, in the East, Greek science still faced a tough struggle not to perish in the motherland of magical science. Time and again the struggle seemed lost, but time and again the rational element was able to again raise its head.

This rough sketch of pre-classical and classical science and technology may bring little that is new – its primary aim is to demonstrate how many problems still await solution. What is true of other domains of science and technology is true here too. The outlines have been traced, but much detailed work must be carried out before the lines can be clearly drawn. More than anywhere else a 'back to the texts' approach is urgently required. We may speak of a young tree in the forest of the sciences. It will be able to grow to full maturity and fruition, if under our care it can develop a roof of foliage which stimulates its vital functions.

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[20]M. Meyerhof, "On the Transmission of Greek and Indian Science to the Arabs," *Islamic Culture* 11, 1937, pp. 17-29.