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The Precursors of Scientific Models in Ancient Egypt, Mesopotamia, and Ancient Greek World: A Comparative Study

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Abstract:

This research traces and examines specific examples of the precursors of scientific models that were applied in ancient Egypt, Mesopotamia, and the ancient Greek world. The main purpose of the study is to compare the way that these different civilizations used models but also the purposes of their utilization in pre-Hellenic and ancient Greek science. A core question that arose is: Can we trace the roots of the utilization of what we nowadays call "scientific models" in ancient Egyptian, Mesopotamian, and Greek scientific activity? Another important question is how the application of models differs in the scientific activity of these civilizations. Based on an extensive review of historical books, papers, and web sources I inferred that ancient Egyptians and Babylonians utilized tools that nowadays we call mathematical and analogue or material models and the ancient Greeks utilized theoretical, fiction, and analogue models. Moreover, while the basic function of these tools seems to remain stable throughout the centuries, the core difference is detected in the purpose of their utilization in these civilizations and is related to the orientation of their scientific activity. Specifically, the scientific activity of Egyptians and Babylonians mainly aimed at solving practical problems related to spatial planning, architecture, and agriculture as well as issues related to religion while ancient Greek "episteme," according to Plato, or "natural philosophy," according to Aristotle, sought the acquisition of knowledge about the natural world, the understanding, description, and explanation of natural phenomena.

Keywords: *scientific model, science, technology, pre-Hellenic science, ancient Greek science.*

Introduction

In recent decades, philosophers of science have engaged in an endless dialogue concerning the understanding and defining of the concept of the scientific model (e.g., Susan Sterrett, Roman Frigg, Stefan Hartmann, Axel Gelfert, etc.). They extensively discuss issues related to the nature, categories, and function of scientific models, the purposes of scientific models' utilization, but also how we learn through their experimental application. Several philosophers focus on the contemporary use of scientific models in various scientific fields, while others examine examples of models' application come from the 18th, 19th, and 20th centuries. On the contrary, just a few scattered references to models from antiquity can be traced in modern philosophical and historical literature. So, we could say that the investigation of the roots of scientific modeling is somehow neglected in modern history and mainly the philosophy of science.

However, scientific modeling techniques did not appear suddenly after the Scientific Revolution and the Enlightenment. The roots of the

utilization of this powerful technique can be identified in ancient civilizations in a manner that was serving their needs in the corresponding historical contexts that consisted of and determined by specific social, political, and religious factors as well as factors related to the scientific and technological development of each period. Therefore, the roots of the invention, construction, and utilization of the tools we nowadays call scientific models must be further examined by historians and philosophers of science. Recognizing the existence of this specific gap, in this study we will seek to trace the roots of the scientific modeling technique back to antiquity and compare the function and purpose of models' utilization between pre-Hellenic civilizations and the ancient Greek world.

The term "model" was introduced at 88 AC by the Roman architect, writer, and engineer Vitruvius in his treatise entitled *De Architectura* in which he defined a measure corresponding to half the cross-section of a column, which he was using to formulate and express all the relationships of a construction. Later the Latin term "modulus," which is rendered as a unit of measurement, entered European languages, means the form of a thing which was made according to the right measure. The newer term "model" comes from the Italian word "modello" which means pattern or exemplar, which, at least at the first stage, is mainly associated with three-dimensional geometric visualization with scale (Christodoulidis, 1979). The concept of the model is associated with the concept of image or representation combined with the concept of construction and, we could say, with the function of the model as a "consistent representation," as Maxwell had mentioned (Christodoulidis, 1979). In the modern philosophy of science, the concept of a scientific model is often attributed either as the representation of a physical object, phenomenon, or system or as the interpretation of theories (Rogers, 2012; Frigg and Hartmann, 2020) while in the past it was also attributed as structural isomorphism, as an equivalence of structural relations (Christodoulidis, 1979). Despite that the term model cannot be traced before 88 AC, the history of science provides us with various examples of tools and techniques, that resemble what we call today scientific models concerning their form and mainly their function even from the times when the roots of science were traced.

Several historians support that the roots of science and the development of various scientific techniques are traced to ancient Egyptian and Babylonian scientific activity (Grigoriadou et al., 2021; Lindberg, 1997; Speiser, 1942). To control nature and ensure better living conditions, the ancient Egyptians and Babylonians observed the natural world, the sky, and the human body and applied various techniques to find solutions to everyday problems. In this manner, they developed specific techniques to control nature, but they did not focus on the definition of the general principles beyond these techniques. Therefore, they set the foundations for the future development of various scientific fields such as astronomy, mathematics, geometry, medicine, and engineering. In the context of Egyptian and Babylonian astronomy, not only mathematical models were developed but also analogue or material models, which are representations of physical systems, and which were used in a manner that was quite similar to modern scientific models in terms of their function, but not necessarily in terms of the purpose of their use.

Other historians insist that the precursor of modern science was episteme, which appeared during the classical era and was introduced by Plato with the meaning of knowledge or the process of understanding (Andrew, 2007a; Farrington, 1989; Grigoriadou et al., 2021; Lindberg, 1997; Moss, 2020). According to Aristotle science corresponds to a deductive valid system grounded in necessary truths about natures or essences and he distinguished it from techne which is a kind of practical knowledge relating to what we nowadays call technology. In this respect, the purpose of the philosophical or scientific activity of the classical era was to formulate theories to describe and explain the natural world (Grigoriadou et al., 2021). In other words, ancient Greek philosophers, natural

philosophers, mathematicians, and doctors based on the empirical, and scattered knowledge that came from the pre-Hellenic cultures and created an organized and solid system of knowledge that was based on general principles and theories (Farrington, 1989). Thus, the intellectual activity of the ancient Greek world was closer to the "episteme concept," while the intellectual activity of ancient Egypt and Mesopotamia seems to resemble what Aristotle called "techne." On this basis, the roots of the scientific techniques, and the tools, such as scientific models in these civilizations, should be examined in these general contexts.

The core questions that arose here are: What kinds of models are traced in ancient Egyptian and Babylonian science and what in the ancient Greek world? How did these different civilizations apply models and why did they use them? In other words, how the application of models differs in the scientific activity of these civilizations? Finally, what was the relationship of the precursor of scientific models to the nature and application of the corresponding contemporary scientific models? To address these points, we will examine four cases of models' application in Egyptian and Babylonian scientific activity and four examples of scientific models that come from the ancient Greek world. Then we will compare the function of these tools, the way that they were applied, and the purpose of their utilization through the scientific activity of these civilizations.

Models in Ancient Egyptian and Babylonian Scientific Activity

The ancient Egyptians systematically dealt with the fields of mathematics, astronomy, and medicine, laying the foundations for the subsequent development of these scientific fields (Lindberg, 2003). Examples of the use of models are found in Egyptian astronomy, medicine, geometry, and architecture.

An interesting example of a precursor of an analogue or material model, which is often defined as a physical setup that represents another inaccessible or difficult-to-access physical setup based on a specific similarity between them (Sterrett, 2005, 2017), is the case of "temple or building models" in Ancient Egypt. The ancient Egyptians observed the night sky, and the distances between specific stars, and usually aligned their pyramids and Sun temples with the four cardinal points of the earth. More specifically, Egyptian astronomers observed Ursa Major and Orion with an instrument similar to an astrolabe which was called a *mercket,* and aligned the foundations of the pyramids with the positions of these constellations with remarkable accuracy (Canadian Museum of History, 2019). Moreover, some Egyptologists argue that the three pyramids of Giza represent the three stars in Orion's belt, the Sphinx represents the constellation Leo, and the Nile represents the Milky Way galaxy. The idea of creating a sacred landscape on Earth that reflects the night sky was not uncommon in ancient cultures. However, the Egyptian temples were not just the houses of the gods, but they were also representations of the universe (Memphis University, 2019). On this basis, the Egyptian temples and pyramids could be perceived as analogue models representing specific stars as they achieved to align the foundations of these buildings with the positions of these constellations with remarkable accuracy.

But how were these kinds of models used by Egyptians and what was the basic purpose of their application? If we accept the opinion according to which these temples were representing the houses of gods, we are obviously in front of a different function and purpose of utilization of modern scientific models. In this case, perhaps is safer to speak about symbolism than representation which is the core function of analogue models. But was this the only purpose of this kind of model? A second view is that the temple or building models were representations of specific constellations, as we have already mentioned. Based on this opinion astronomers used this kind of analogue model to make observations and predictions about specific astronomical and physical objects, systems, phenomena, and situations. In this case, the utilization of temple or building models presents important

similarities to contemporary scientific modeling as through these tools ancient Egyptians could make predictions about specific phenomena that they couldn't observe otherwise. But why did the ancient Egyptians use temple models? Why did they try to make this kind of prediction? One reason is related to the prediction of the changes in the seasons and more specifically the arrival of the summer monsoons or the flooding of the Nile to take the necessary measures regarding their crops or their movements (Canadian Museum of History, 2019). Therefore, the pyramids or even the religious temples can be characterized as analogue models that were used to facilitate the observation of the movements of the stars, and the sun along the horizon to solve practical problems of everyday life in conjunction with religious ceremonies. Therefore, using temples as models of the universe may not have served the same purposes as modern models; however, this makes sense as they were formed 5.000 years ago and under very different social, religious, and technological conditions. In this context, Egyptian monuments such as pyramids and temples could be considered ancestors of the logic of construction and operation of modern scientific analogue models.

Furthermore, Egyptians made significant achievements in the field of medicine as arises from the medical papyrus of Ebers, Edwin Smith, Hearst, and the London Medical Papyrus (Grigoriadou et al., 2021; Lindberg, 2003; Nunn, 2002). Can the use of models be traced back to ancient Egyptian medicine? According to several archaeologists, ancient Egyptians did anatomy on animals and embalmed them. This belief is based mainly on monument murals depicting doctors examining dead animals and was enhanced by the discovery of a large number of mummified animals in the Sahara in 2018 (BBC, 2020). Archaeologists support that ancient Egyptians mummified animals for several reasons; either as offerings to gods, or as food offerings to humans in the afterlife, or even they were embalming ancient Egyptians' household pets and buried them with their owners (Pruitt, 2018). In the first place, this activity seems totally different from the utilization of models of organisms and more specifically animal models in modern science. However, there is a commonplace between these two techniques. They both are based on the mechanism of similarity. The similarity is a core mechanism that determines the application of analogue models (and their sub-category animal models) and it corresponds to identifying, verifying, or maintaining an analog relation, feature, attribute, or behavior between two systems, between the model and the target system that represents it. In the case of animals' mummification, similarity also played an important role, as the Egyptians had to recognize similarities among the organisms, the organs, and their functions, based on their existing empirical knowledge to embalm animals. In this respect, the basis of animal models' function, which is the utilization of the mechanism of similarity, can be traced here.

Moreover, an important source of knowledge for the ancient Egyptians was the embalming of human bodies. The study of bodies through anatomy enabled Egyptian physicians to learn about the function of the human body, its skeleton, and its organs. In this respect, the dead human body could be perceived as a kind of analogue model of the human organism. We could call this kind of model the "dead model." The main purpose of this process was religious as according to their beliefs the embalming was necessary to sustain the soul on its way to the afterlife. Maybe the core reason that Egyptian priests-doctors developed the technique of embalming and utilized the "dead models," was religious, although through this process they gained knowledge about the human organism. Therefore, the ancient Egyptian priests-doctors relied on similarity to a significant extent both during the stage of studying the human organism and during the stage of categorizing the existing knowledge about it through the medical papyruses (Grigoriadou et al., 2021).

Another example of a precursor of models comes from Mesopotamian science and corresponds to mathematical modeling. Mathematical modeling is often defined as "the conversion activity of a real problem in a mathematical form and it involves formulating real-life situations or converting the problems in

mathematical explanations to a real or believable situation" (Dundar et al, 2012). Therefore, a mathematical model can be perceived as a representation in mathematical terms of the behavior of real devices and objects (Dabbaghian, 2014). The ancient Babylonians had significantly developed mathematics, which they used systematically for astronomical predictions and astronomy mainly for calendrical, religious, and practical reasons related to agriculture (Lindberg, 1997). They observed the sky, the movements of the stars and the sun and distinguished the agricultural seasons based on the position of certain constellations to the sun (Lindberg, 1997). From the Assyrian period (700 BC) onwards, a shift is observed in the mathematical description of the movement of the planets and the moon (Neugebauer, 2003: 136). About 500-300 BC Babylonian astronomer-priests managed large amounts of astronomical predictions utilizing mathematical models in the form of numerical progressions that allowed them to track the daily movements of the sun and Selene in the zodiac circle (Lindberg, 1997). This fact is also confirmed by the astronomical catalogs they compiled, the study of which led to the discovery of complex regularities in the movements of the heavenly bodies (Lindberg, 1997). In ancient Mesopotamia, therefore, the roots of mathematical models can be found, the operation of which was based on numerical methods that allowed the projection of past observations into the future (Lindberg, 1997). Babylonian mathematical astronomy relied on relationships between periods, which state that one kind's intervals are equal to another's. An example is a helio-lunar rule which presupposes the existence of a relationship in which m lunar months are equal in duration to n lunar years (Neugebauer, 2003). The use of these mathematical models helped predict the arrival of the new moon and lunar eclipses, information that was important to calendrical matters such as calculating the length of night or day during the year.

We don't know either if there was a term for the tool that today we call model or if the ancient Egyptians or Babylonians had defined the method of modeling in the context of their intellectual activity. However, through the examination of the above specific examples we conclude that at least mathematical and analogue models were systematically utilized by these civilizations as tools contributing to the description of specific objects, systems, and organisms or for prediction about specific phenomena, aiming mainly at solving practical problems or serving religious purposes (Grigoriadou et al., 2021).

In this respect, the precursor of the logic of scientific modeling can be traced in ancient Egyptian and Babylonian science, which, in parallel with the scientific activity of this period, mainly aimed to solve everyday problems and not primarily to acquire scientific knowledge *per se*. This is also a core difference between the use of models in these cultures compared to their systematic and conscious application in modern science, which mainly aims, among other things, to the acquisition of scientific knowledge.

Models in Ancient Greek Science

The ancient Greeks seem to have left their mark in the continuous effort to study and explain the natural world, aiming not only to find practical solutions to everyday problems but also to understand, describe, and explain natural phenomena. Ancient Greek natural philosophers were interested in the acquisition of knowledge about the natural world. In this context, through their scientific activity, they contributed to the transition from technology to science (Farrington, 1989). This opinion can be confirmed by their attempt to conceptualize the process of acquiring knowledge about the natural world, which was called "episteme" by Plato and "natural philosophy" by Aristotle. Ancient Greek natural philosophers seem to have consciously tried to gain the knowledge about natural world. But did ancient Greeks use scientific models? And if so, what categories of models can we trace in this period and how were they used by the ancient Greeks philosophers, natural philosophers, and physicians? To address these points, we choose and will examine four examples of models of the ancient Greeks that

can be considered important milestones in the development of astronomy, cosmology, physics, and medicine, which continue to attract the interest of modern historians of science, natural scientists, doctors, and researchers in general.

The first and perhaps the more famous model we will examine here is Ptolemy's geocentric model, which is a theoretical model; the second is the theory of Democritus about the atomic structure in which the roots of the first fiction or imaginary model can be traced. A fiction or imaginary model could be defined as a mental construction that represents physical objects, phenomena, or situations, which are difficult or impossible to observe (Frigg and Hartmann, 2020). A third example is the animal models used in ancient Greek medicine of, the Father of medicine, Hippocrates 5 century BC and of Galen during the Greco-Roman period. Animal models are a sub-category of models of organisms that are kinds of analogue models widely utilized mainly in biomedical sciences.

The ancient Greeks had dealt extensively with the observation of the stars, the sun, and the movement of the planets, while it seems that they had made use of Egyptian and Babylonian astronomical knowledge. This resulted in the formulation of several important theoretical models of the sky (Andrew, 2007b). A well-known example is the geocentric model, a theoretical model introduced by Ptolemy which was widely accepted for 1500 years (Andrew, 2007b). According to Ptolemy's model, the Earth is at the center of the universe and all the other celestial bodies revolve around it. The Earth is spherical, stable, and larger than all the celestial bodies. Moon, Mercury, Venus, Sun, Mars, Jupiter, and Saturn revolve around the Earth performing smooth circular motions or epicycles, while the rest of the stars stand on an outer sphere. An epicycle is a combination of two smooth circular motions, which do not have a common circular center and the center of the smaller circle revolves around the larger circle. The movement of the planet depends on the size and speed of rotation of both circles. Therefore, several complex trajectories arise. In addition, Ptolemy's model was based on two other mechanisms: the eccentric circle, a circle whose center does not coincide with the center of the Earth, and the equator (Andrew, 2007b; Lloyd, 2003). The equator corresponded to the point from which a hypothetical observer would see the planet revolving around him in an epicycle, traversing equal angles at equal times. The model was mathematically substantiated, which allowed the safe explanation of many astronomical phenomena (Andrew, 2007b). By utilizing the geocentric astronomical model, Ptolemy could explain the change and brightness of the planets, and the variations observed in their velocities, and in addition, he could provide figures of retrograde motion and accurately explain this phenomenon (Andrew, 2007b). It provided the possibility of visualizing and predicting the orbits of the Sun, the Moon, and the known planets on the level of the ecliptic. The geocentric model was so accurate that it prevailed until Copernicus established the heliocentric system, which had been proposed earlier by Aristarchus of Samos (310-320 BC) (Andrew, 2007b). Therefore, Ptolemy's model was a theoretical model, mathematically substantiated, describing complex and inaccessible systems and phenomena. Despite that we do not accept this theory today, the purpose of the utilization of the geocentric model is similar to the contemporary utilization of theoretical models in natural sciences which often describe and explain natural objects, phenomena, systems, and mechanisms.

Another example is the atomic theory which appears to have been invented by Leucippus and elaborated and developed by Democritus. Their basic idea was that everything in the universe consists of atoms that are tiny particles, invisible, in constant motion. Atoms are of different types with different shapes and sizes, and they combined in different manners to form different substances (Annunziata, 2007). Through their theory, they aimed to describe the structure of matter and they proposed a fiction model, an imaginary arrangement according to which there is a void within which exist these distinct, indivisible, and unchanging smallest particles of matter, the atoms. Atoms move through the void and arrange themselves in various combinations and formations, which accounted

for the change in the world and from which everything else is composed. Leucippus and Democritus invented an imaginary or fiction arrangement, a fiction model, based on which they sought to describe particles which due to their size could not be observed directly and gave an acceptable answer, specifically for this period, regarding the structure and changes of matter.

Another interesting example of an early scientific model comes from the field of ancient Greek medicine. Although the first therapeutic practices are attributed to ancient Egyptian and Babylonian healers, the roots of systematic medical science are placed in the school of Hippocrates during the 5th century BC. as the Hippocratic doctors believed that diseases were not a kind of punishment coming from the gods to people for their sins but were due to some natural cause, which the physician is called upon to identify and eliminate (Andrew, 2007b). The Hippocratic doctors established scientific medicine through a large list of writings in the Hippocratic Collection (Corpus Hippocraticum), based on experiment, observation, and logic. They progressed to observing symptoms, developing therapeutic practices, and trying to predict diseases (Andrew, 2007b). In this context, they consciously utilized tools that we nowadays call models of organisms and more specifically animal models that were characterized by specific similarities with human physiology. These models were used during the experiments of Hippocratic physicians to understand, describe, explain, predict, and treat specific diseases. An example was the utilization of dead goat heads to understand and describe the sacred disease, epilepsy (Andrew, 2007b). Until the time of Hippocrates, epileptic seizures were attributed to the possession of the patient by the gods, in other words to divine intervention. The Hippocratic doctors were not accepting any other cause of disease than a natural cause. Therefore, they carried out experiments with animal models, more specifically they examined animals that exhibited similar symptoms. For instance, having noticed that goats have a similar disease to epilepsy, which is characterized by similar symptoms, they proceeded to anatomy and study goat brains. So, they noticed that the brains of goats that had suffered from a disease similar to epilepsy were wet and smelled bad (Andrew, 2007b; Lloyd, 2003). In this case, the goat brain was used as a model of the human brain suffering from epilepsy. The Hippocratic doctors, therefore, using the specific models, proved that the brain of a goat that had seizures similar to epileptics had a different texture and smell than that of a healthy goat, which enhances the view that the cause of the disease was natural and not divine. According to the Hippocratic doctors, if this was true in the case of goats, it was also true in the case of humans, as the cause of the disease was due to the accumulation of fluid around the brain (Lloyd, 2003). In this sense, goat heads functioned as analogue models of the human brain due to the similarity of epileptic seizure symptoms between goats and humans and were used to identify the underlying physical cause of the disease in humans.

The use of animal models was further expanded during the Greco-Roman period by Galen (2nd century AD), who systematically dealt with the anatomy and physiology of the human body and urged physicians to observe not only the human body but also the body of living or dead animals. Specifically, Galen urged physicians to anatomize dead soldiers, and animals that were similar to human organisms, such as monkeys, to be able to describe the organs, bones, viscera, and the body internally (Lloyd, 2003). Observing apes, Galen argued that compared to other animals, they are the most similar to humans, in terms of viscera, muscles, arteries, veins, nerves, and the arrangement of bones (Andrew, 2007b). Galen used a significant account of animals as analogue models in his experiments, including pigs, goats, monkeys, and even an elephant (Lloyd, 2003). An example is the experiments he carried out on a living pig in his attempt to clarify which parts of the body are controlled by the nerves emerging from the spinal cord. He was sectioning the pig's spinal cord at the height of each vertebra in an ascending direction and observing which functions of the pig ceased with each section (Andrew, 2007b).

Examining these examples, we notice that although no written sources have been identified that explicitly mention and define the concept of the scientific model in the context of ancient Greek science, the modeling technique was consciously used, sometimes more sometimes less systematically in various areas of ancient Greek intellectual activity like its modern application. We also notice that different categories of models were used, theoretical models such as Ptolemy's geocentric model, fiction, or imaginary models such as Democritus' model of the structure of matter, but also analogue models, such as the animal models that were used by Hippocrates and Galen. In these cases, the invention, formulation, or selection of each model was aimed at gaining knowledge about a system that often could not be examined directly. So, these natural philosophers and doctors modeled the system they wanted to investigate, describe, explain, and be able to make predictions about it, with satisfactory accuracy for that time. The purpose of inventing, selecting, or constructing models in the ancient Greek world seems to be quite similar to the corresponding purpose of their application in modern science. Therefore, just as the roots of science are placed in ancient Greece, the roots of the conscious use of scientific models must also be placed in ancient Greek scientific methodology.

Conclusion

From the previous discussion, we conclude that the precursor of the logic of scientific modeling technique can be traced back to ancient Egyptian and Babylonian science but the roots of the conscious construction, invention, and utilization of scientific models to gain scientific knowledge *per se* are traced back to ancient Greek intellectual activity following the main purpose of this activity. The core difference between Egyptian and Babylonian science to later ancient Greek science is their orientation toward solving practical problems related to spatial planning, architecture, and agriculture as well as issues related to religion. Thus, the models during this period were used to serve primarily this purpose despite that they also led to the acquisition of important knowledge in various fields such as that of astronomy and medicine.

An interesting observation that emerged from this approach is related to the correspondence of different kinds of models that were utilized centuries before with models in modern science. Specifically, we identified Ptolemy's geocentric model, which is a theoretical model, the Democritus atomic theory which can be perceived as a fiction model, the Babylonian mathematical models of astronomy, and the analogue models such as the Egyptian "temple or building models," the Egyptian "dead models" and the animal models used by the ancient Greek doctors, the Hippocratic doctors and Galen.

These kinds of models that were used in ancient times are also applied in the contemporary methodology of various scientific fields. This observation leads to a very interesting and important inference that can be summarized in the idea that although the characteristics of scientific activity and scientific thought differ from one historical stage of evolution to another, the technique of the scientific model exists and appears with similar forms, even with a different function, even if it serves a different purpose, in different spatiotemporal contexts, in different stages of development of scientific thought, scientific methodology and more generally of this intellectual activity that we call today science. The presence of scientific modeling techniques in different periods of development of scientific thought and practice leads to the conclusion that it is completely intertwined with the process of knowledge acquisition. Thus, scientific modeling is an integral component of scientific methodology, an essential tool of science.

Conflict of interests

No conflict of interest.

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