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Ancient Mesopotamian Mathematics Provides an Early Example of the Inextricable Links Between A Society's Worldview, the Application of Technology, and the Development of Science.

By

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Archaeological research[1] covering a 6,000 year period in the Tigris and Euphrates river valleys, shows that the classical high cultures of the ancient Near East demonstrated some of the earliest and most fundamental examples of systematic observation of phenomena and prediction, unsurpassed until the European Renaissance, and practical engineering, unsurpassed until the 19th century. Though clearly an advanced technological society, Mesopotamia (modern Iraq, with imperial influences in Syria, western Iran, and southern Turkey) left records on cuneiform tablets that indicate the society had an advanced capability in mathematics, based on a sexagesimal system. This system, based on 60, may seem quite odd to the casual observer. But to the Sumerians, Akkadians, Babylonians, and Assyrians of ancient Mesopotamia, it reflected the practicalities of daily life governed by astronomical cycles and the natural rhythms of the alluvial plain. A study of their mathematics shows one how practical record keeping set the stage for advanced abstract thinking, which influenced the Greeks and remain the foundation of the modern scientific method.[2]

It is very easy for the modern citizen of a technologically dependent society to assume that the social structure and human interactions are being driven by the unfettered, and often

[1] The study of ancient Mesopotamian archaeology is relatively recent, within the past 150 years, and is based largely upon the abundance of decorated pottery, bas-relief steles, and texts written on unbaked clay tablets. Over 500,000 cuneiform tablets have been recovered from sites in the Near East. (Roaf 14) Much of the organic matter has disintegrated over the years.

[2] But just what do we mean by the word *'science'*? For our purposes, let us define *science* as the body of knowledge obtained by methods of observation. It is derived from the Latin word *scientia*, which simply means knowledge, and the German word *wisenschaft*, which means systematic, organized knowledge. Thus, science, to the extent that it is equivalent to wisenschaft, consists not of isolated bits of knowledge, but only of that knowledge which has been systematically assembled and put together in some sort of organized manner (Fischer 5-7). In particular, the science with which we are concerned is a body of knowledge that derives its facts from observations, connects these facts with theories and then tests or modifies these theories as they succeed or fail in predicting or explaining new observations. In this sense, science has a relatively recent history, perhaps four centuries (Platt).

unintentional, consequences of a spiral of accelerating technological developments.[3] Likewise, it has become fashionable for warnings of the potential evils of technology to be screamed from the pages of prophetic socio-political novels and science fiction films. However, on the contrary, a careful study of the history of technology shows that, rather than it being the driver of society, indeed society's values, motivations, beliefs, and worldview drive and shape the evolution of technology.[i] Also, it is common to find abstract science standing on the shoulders of historical techniques and technological innovation.[4] This has been the case since the earliest of recorded history.

Ancient Mesopotamia offers a case study in just such a controversy. Many science historians argue that Mesopotamian advanced civilization was purely the result of applied engineering and skilled trades.[5] They correctly argue that practical knowledge embodied in the crafts is different from knowledge derived from some abstract understanding of a phenomenon (McClellan 13). They believe that Mesopotamia achieved this level of advancement without the kind of abstract science and mathematics, later practiced by the Greeks. Alternatively, archaeologists, such as Jean Bottero of the Ecole Pratique des Hautes Etudes in Paris, argue that Mesopotamia indeed practiced an early form of abstract thinking and used mathematical astronomy as the bridge between engineering and science.

Before examining the mathematical system and its role, it is important to put its development into a proper cultural and historical context.[6] Mesopotamian society is perhaps the first known *civilization*, in the strictest sense of the word.[7] About 5,000 years ago, the emergence

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[3] Technology is how society does things, not how it thinks of them. Suffice it to say for our use that *technology* is science plus purpose. While science is the study of the nature around us and subsequent development of scientific 'laws,' technology is the practical application of those laws, in sometimes non-rigorous ways, toward the achievement of some material purpose (Dorf 1).

[4] There are intimate relationships between *science* and *technology*; yet science is not technology and technology is not science. Technology relies very heavily upon basic scientific knowledge in addition to existing technologies. There is also a strong influence in the reverse direction. Modern science relies to a large extent upon current technology as well as prior scientific knowledge. Science and technology reinforce each other by complex interactions. Each one, science or technology, can build upon itself or upon a linkage from one to the other. Indeed, science is not technology and technology is not science, but they are firmly interrelated. One could not exist in modern society without the other. (Dorf)

[5] Some of these proponents include Stevens Institute of Technology's James E. McClellan III and Harold Dorn, British historians T, K, Derry and Trevor I. Williams, and City College of New York's Thomas Goldstein.

[6] After the last Ice Age, the people in the land between the Tigris and Euphrates rivers, in what we now know as Iraq, moved from the hunter-gatherer way of life, which had proved effective for hundreds of thousands of years to a more settled Neolithic village lifestyle, based on the domestication of plants and animals about 12,000 years ago. The Near East is encircled by the Mediterranean, Black Sea, Caspian Sea, Persian Gulf, and the Red Sea. The Zagros Mountains of Iran are to the east, the Taurus Mountains of southern Turkey are to the northwest, and the great Nafud and Syrian deserts are to the west. There is a distinct lack of rainfall throughout the entire region during the summer months. The region has sufficient rainfall for dry farming, but irrigation increases the yields and extends the growing season so that more than one crop per year can be harvested (Roaf 19-23). Fortunately, the people of Mesopotamia have been able to rely on the snowmelt from the mountains and the cyclical flooding of the Tigris and Euphrates over a very broad alluvial plain. Layard's journal notes that the Tigris and Euphrates do not overflow their banks like the Nile, depositing rich soil over the land. They rise sufficiently at a time of the melting of the snows in the Armenian mountains, to fill the small waterways that lead from them. He also notes that when the rivers are low in summer and autumn, the water can only be raised by artificial means. Layard concludes that if a season passes without rain, and a drought is the result, there is great misery and suffering throughout the country (Layard 304-305).

[7] Urban-based civilizations unfolded independently in multiple centers across the world. A pattern of Neolithic settlements coalescing into centralized kingdoms based on intensified, hydraulically enabled, agriculture occurs at least

of ruling classes, religion, writing, and cities formed the standard ingredients of what we refer to as *civilization* (Roaf 19). This rich delta, and some very ingenious hydraulic engineering by the Mesopotamians, allowed for extensive irrigation[8] and highly productive farmlands.[9] The great British archaeologist Austen Henry Layard, in his 1845-1847 expedition journal cites and agrees with Herodotus, who described the fertility of Assyria as having "abundant harvests of corn, the seed producing two and three hundredfold."[10] However, Layard also notes that, "In his [Herodotus'] day, the Assyrians depended as much upon artificial irrigation as upon the periodical rains. They were skillful in constructing machines for raising water, and their vast system of canals was as remarkable as a monument of well-directed labour, as for the knowledge of hydraulics which it displayed" (Layard 305). Under the influence of irrigation, "Former subsistence-level farming gave way to the production of large surpluses of cereals that could be taxed, stored, and redistributed," according to James McClellan and Harold Dorn of the Stevens Institute[11] (McClellan 31). In addition, village life facilitated new forms of technologies, such as metalworking, pottery, stone carving, and new forms of social organization. Religion and rituals also played a fundamental role in the life of Mesopotamia.[12] Given its precarious dependence on water from cyclical river flooding and the critical nature of the rebirth of crops, it is not surprising that Mesopotamian religion dominated so many aspects of society. As the University of California's Michael Roaf notes, "…religious centers acted as focal points for the surrounding regions and concentrated wealth and power through gifts to the temples or through tax" (Roaf 65). As the society grew in numbers and geographic size, as water and land had to be distributed, as squabbles had to be settled, and as Mesopotamian civilization became more

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six times in different sites: Mesopotamia after 3500 BC, Egypt after 3400 BC, Indus River Valley after 2500 BC, along the Hwang Ho (Yellow River) after 1800 BC, Mesoamerica after 500 BC, and South America after 300 BC (McClellan 32).

[8] The history of Mesopotamian cities, kings, and warfare is also tied directly to the control of an abundant and reliable water supply. (Roaf 110). For example, Hammrabi captured Eshnunna by diverting the waters around the city. In the 7th century BC, the Assyrian king Sennacherib dammed the river Tebitu ten miles north of the city (and later dug a canal overland from 30 miles away), created a reservoir, and re-routed the flow of a canal through the middle of Nineveh before it emptied into the Tigris (DeCamp 62-63)

[9] McClellan and Dorn argue that environmentally restricted agricultural zones bounded by desert, cataracts, and sea, beyond which traditional farming was possible or practical, coupled with the expanding Neolithic populations, drove the need to intensify food production. This led to creative use of the water management, canals, and irrigation (McClellan 33).

[10] According to Layard, "The blades of wheat and barley…grew to full four fingers in breadth; and such was the richness of Babylonia, that it supplied the Persian king and his vast army with subsistence for four months in the year, while the rest of the Persian dominions furnished provisions for the other eight (Layard 305).

[11] Increased crop yields allowed for further growth of cities into city-states and enhanced the social stratification into classes and skilled specialties. This urban revolution sustained armies, tax collectors, a priestly class, and centralized political authorities (McClellan 31-32). Great walled cities, such as Uruk, Ur, and Sumer supported populations between 50,000 and 200,000.

[12] Excavations of 14 levels of the large Anatolian site of Chatal Hayuk show decorated shrines, figurines of mother goddesses, birth goddesses, and bull-horned male deities, as far back as 6850 BC (Roaf 43-44). Ubaid period (5000 BC) temples at Eridu were built to worship the water god Enki on an early pattern of platforms that signaled the future development of ziggurats devoted to religious ritual (Roaf 53-55). Uruk, also known in the Bible as Erech and the legendary home of the Sumerian king Gilgamesh, was a large city of over 400 hectares and an important site for the worship of the goddess Inanna (later known as Ishtar) in the 4th millennium (Roaf 58-62).

acquisitive and complex, the kings began to regulate society through codified laws.[13] Increased crop yields, surpluses, and wealth led to a desire to trade with neighbors, even distant ones, for luxury items and raw materials.[14] Ultimately, the city-states were conquered and consolidated into empires. It is from these empires that the famous monumental building projects were organized, funded, and developed.

Mesopotamia shows evidence of being the most advanced technological society of its era.[15] Over a 6,000 year period, Mesopotamian technology included advances in carpentry, glassmaking, textile manufacture, leather-working, perfume-making, farming, food preparation, irrigation, flood control, canal-building, water storage, drainage, brewing, and their tablets also provide detail on the economics of various industries (Roaf 126). The most basic indication of a settled, rather than nomadic, lifestyle is pottery. Decorated pottery found at Tell Hassuna[16] indicates a mastery of kilns providing higher temperatures for baking non-porous jars as early as the middle of the 7th millennium BC (Roaf 39). "During the 4th millennium, there were major developments in metallurgy," according to Roaf. Smelted copper, alloys of copper and arsenic, lead, gold and silver ornaments benefited from the use of lost-wax casting techniques (Roaf 72). Sir Leonard Woolley's excavations of more than 1,000 graves in the Royal Cemetery at Ur show a complete mastery of jewelry making techniques using composite objects, inlaid stones, and sophisticated geometric designs (Roaf 92). Intensified agriculture based on large scale water management networks constructed and maintained as public works by conscripted labor gangs (corvee) and slaves under the supervision of state-employed engineers is the critical foundation of their civilization[17] Main canals were nearly 75 feet wide, had hundreds of connecting channels, and ran for several miles (McClellan 31-35). Perhaps the most impressive engineering achievements of ancient Mesopotamia are the series of ziggurats found throughout the region as early as 2100 BC in Ur, 1900 BC in Babylon, and 900 BC in Assyria.[18] In addition, the Assyrians of Nineveh under the leadership of Sargon II (722-670 BC) and his son Sennacherib dominated the Near East with its iron-equipped armies, battering rams, and horse-drawn chariots (Derry 12).

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[13] Though law codes existed before his time, the most notable of the old Babylonian kings is Hammurabi (ruled 1792 to 1750 BC) whose codification of 282 sections of practical laws provided guidance to judges on commercial, family, and property law (Roaf 121). It also demonstrated how significantly his society was stratified, given that the three social classes – *awilum* (free man), *muskenum* (worker or soldier), and *wardum* (slave) – had drastically different penalties for the same infractions. (See Theophile J. Meek's translation of the *Code of Hammurabi*.)

[14] A healthy commercial trading relationship existed between Mesopotamia, the Levant, Egypt, and as far away as Afghanistan and Pakistan. For example, by the 4th millennium, semiprecious lapis lazuli beads were found in large numbers in tombs at Tepe Gawra in northern Mesopotamia. Roaf notes that one tomb at Tepe Gawra had 500 lapis lazuli beads in it. The closest source of lapis lazuli was over 2000 kilometers away in the Badakhshan province in northern Afghanistan (Roaf 66).

[15] The first use of the plow in the Near East dates back to the Uruk period. Sledges, wheeled vehicles, boats, and overland animal caravans have been used in Mesopotamia since the 4th millennium (Roaf 72).

[16] A *Tell* is a mound of successive civilizations built on top of each other.

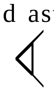
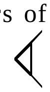
[17] McClellan and Dorn note that chronic warfare led the victors to, not only take over land and smaller irrigation works, but subjugated the defeated groups, sparing their lives in return for their labor as slaves and peasants in maintaining systems of intensified farming (McClellan 33).

[18] These massive and towering series of superimposed brick platforms dominated the city's landscape and were the centers of religious ritual. The most famous ziggurat was dedicated to the god Marduk at Babylon and is the source of the biblical story of the Tower of Babel (Roaf 104-105). This latter ziggurat, built by the neo-Babylonian or Chaldean emperor Nebuchadnezzar around 600 BC, rose to over 90 meters (270 feet) and complemented the splendor of the Hanging Gardens and the Ishtar Gate (McClellan 35 and Derry 13).

Writing appeared in Mesopotamia in the 4th millennium BC.[19] According to McClellan and Dorn,

> "Writing and reckoning were first and foremost practical technologies with practical origins meeting practical needs. Knowledge in the first civilizations was subordinated to utilitarian ends and provided useful services in record keeping, political administration, economic transactions, calendrical exactititude, architectural and engineering projects, agricultural management, medicine and healing, religion, and astrological prediction" (McClellan 46-47).

Mathematics was supported by the state and temple authorities, principally to maintain its agricultural economy. For example, 85 percent of cuneiform tablets uncovered at Uruk (3,000 BC) represented economic records (McClellan 47). This administrative nature of mathematics also explained the Mesopotamians' tradition of recording verbal and quantitative information in the form of lists.

The Sumerians invented two different number systems. Administration and business mainly used the *decimal system* based on powers of 10 (1-10-100-1,000, …) and the *sexagesimal system* was used primarily for mathematical and astronomical calculations (Saggs, Civilization 222). They had two numerical symbols,  and , which corresponded to the one and ten of an early decimal system. It is important to recognize that, as Lancelot Hogben notes, "at the most primitive level, people used their fingers and toes for counting." This explains the natural inclination for a base of 10. Grouping strokes on the ground, notches in wood, groups of pebbles, and ultimately counting frames became a regular way to expedite counting and to economize space. In a base-10 system, one only requires nine other signs to express any number of any size[20] (Hogben 35-39). So, it is not surprising that base-10 was the common means to count cattle, small numbers of agricultural products, and to track economic transactions. Likewise, their symbols,  and , worked in a straightforward fashion for numbers smaller than 60. Over 60 the use of the wedge shaped symbols became as cumbersome as the Egyptian and later Greco-Roman notations. So, they developed shorthand versions using combinations of the same symbols in groups, at angles, using spaces, or symbols touching each other (Resnikoff 5-6). What is not as

[19] The earliest known written documents were discovered at Uruk. These pictographic symbols represented words or ideas. By the Early Dynastic period (2,900-2,334 BC) wedge-shaped marks of the cuneiform script had evolved and become widespread as a means to record economic and administrative documents, letters, stories, prayers, and building inscriptions (Roaf 69). Formal schools for scribes, called *edubba* in Sumerian or "Tablet Houses," developed under the sponsorship of the state to promote and transmit knowledge through writing and mathematics. To learn the scribal craft took many years, as the professor emeritus H.W.F. Saggs of the University of Wales quotes a scribe from a text, "You sat in the Tablet House from the days of your youth until your maturity." Scribes were taught to write and compose in both Akkadian and Sumerian languages, which, when fully qualified, enabled one to write vocabularies, sign lists, syllabaries, synonym lists, lists of archaic signs, grammatical paradigms, god lists, commentaries on ancient texts, geographical lists, glass making and pharmaceutical texts, mathematics, and astronomy (Saggs, Babylonians 149). In spite of the scribal curriculum being largely a series of endless copying of exercises and memorizing, the scribal art was highly valued and its practitioners enjoyed high social status (McClellan 47). Much of what we know about the scribal traditions come form the important find by George Smith in 1872 of an extensive library of 30,000 cuneiform texts collected by the Assyrian King Ashurbanipal around 660-640 BC. His library included the standard lists used by scribes, but also bilingual vocabularies, medical diagnoses, rituals, incantations, and the great work of literature, the Epic of Gilgamesh (Roaf 191).

[20] This is true as long as the society has adopted the use of zero. Originally, the Babylonians expressed the concept of a number that contained no element as a widely spaced gap between numbers. But, they eventually invented a special sign for zero and it was in use by 300 BC (Saggs 224-225).

obvious is how the Mesopotamian expertise in astronomy and their knowledge of practical geometry aided the development and selection of a base-60 system for the priestly class.

The sexagesimal digits represented powers of 60 (McClellan 49). Cuneiform script numbers were written using vertical wedges for the units 1 to 9 and diagonal wedges for the multiples of 10 up to 50. The number 60 was written with a vertical wedge, , which could also represent the number 1. Therefore the system used 1, 10, 60, 600, 3600, 36,000, etc. (Kramer 91). They developed a positional or place-value system before 2,000 BC, according to Roaf, and it is still in use (Roaf 125). The sexagesimal place-value notation may be the forerunner of the Hindu-Arabic decimal system we use today (Kramer 290). With a place value system, they were as comfortable as we with the symbol 8 in 78 denoting eight, rather than eighty in 87 (Saggs, Civilization 223). The cuneiform script also used a contextual system to determine the writer's intention. Until 300 BC, the equivalent of a decimal point was not written, nor were zeros. So, as Roaf described, a number could be written as 2x60 + 5x10 + 9x1= 179 or 2x1 + 59x1/60 = 2 59/60 or 2x60x60 + 59x60 = 10,740 (Roaf 125). The scribes were trained to understand this ambiguity based on the context of the problem (Resnikoff 6). According to Samuel Noah Kramer, "Like our decimal system, therefore, the sexagesimal system permits a flexibility in number writing which is highly favorable to the development of mathematics" (Kramer 93).

So, one is led to ask why a sexagesimal system? Why 60 as the base? The answer seems to be tied to the importance of astronomy to Mesopotamia. While even nomads recognized that each star rises and sets a little earlier each day and that lunar time could be tracked, sometime between 10,000 BC and 5,000 BC, settled village communities came to rely more heavily on a seasonal timetable for reaping and sowing that was based on the travels of the sun. As an agricultural civilization, Mesopotamian calendrical systems were based on astronomical observations and were used, not only for agricultural purposes, but also for regulating rituals, dating contracts, and determining future transactions. They had two seasons, *emesh* or summer, beginning in February-March, and *enten* or winter, beginning in September-October (Kramer 91). The year had 12 lunar months of 30 (or 29) days, leading to a year near 360 days[21] (McClellan 51). Days began at sunset and consisted of 12 double-hours, nights had three 4-hour watches, while time was measured by a water clock or *clepsydra* (Kramer 91). A convenient estimate of the year as twelve 30-day lunar months or 360 days allowed for the priesthood to regulate both the ceremonial calendar and the seasonal economy of food production (Hogben 33-41).

They also knew from lunar eclipses that the curved rim of the earth casts upon the moon suggested that the earth was a circular disc.[22] So, the notion of a spherical earth emerged from common practice (Hogben 69). Since they expressed fractions of a circle or sphere in terms of degrees, minutes, and seconds, the Babylonians could correlate the positions of objects in the sky with the time it takes the object to traverse a spherical earth. Also, the number 60 is divisible by a wide range of integers – 2, 3, 4, 5, 6, 10, 12, 15, 20, 30, and 60 – and any proper fraction with these numbers as its denominator can be expressed in minutes only. Likewise, the number of numbers expressible in minutes and seconds is 60 x 60 or 3,600 (Hogben 57-60). So, it is reasonable to infer that the selection of a base-60 system allowed for any practical daily use of fractions to be expressed in 1/60ths, small enough for any calculations the mathematicians of the day had to handle, while it also allowed astronomical use of fractions of a circle or sphere to be expressed in 1/60ths. They also made use of the preexisting base-10 system, common among the people, and

[21] Since this 354 or 360 days is obviously out ofsync with the solar year of 365 ¼ days, an extra lunar month was inserted (intercalated). Babylonian astronomers inserted seven intercalary months over periods of 19 years (McClellan 51).

[22] According to Hogben, nothing in the experience of the temple observatory suggested the contrary (Hogben 69).

rather than rejecting it. They adapted the base-10 system to the needs of the sexagesimal system to, as Hogben cites, "…enable astronomical computation to cope with numbers vastly greater than those needed to catalogue temple property or taxation" (Hogben 58). Likewise, the sexagesimal system permeated Mesopotamian society and the base-60 and its natural divisors can be found in many elements of the culture. For example, Mesopotamian weights were 60 shekels per mina and 60 minas per talent (Roaf 125). Vestiges of the sexagesimal system in modern times can be found in the 60-minute hour, the 60-second minute, and the 360 degrees in a circle (McClellan 49).

The ability to reconcile two mathematical systems into a productive vehicle for practical and priestly use is very impressive. As Saggs notes, "It is true that many of their mathematical procedures were a matter of consulting tables, but those tables must have been devised by people with very high mathematical skills…[exceeding] that of most people today other than those with a degree in Mathematics" (Saggs, Civilization 225).

In addition, they codified their mathematics in two forms for practical dissemination and training of new scribes. These forms were *table texts* and *problem texts*. Sumerian table texts include multiplication, reciprocals, squares, square roots, cubes, and some logarithms (Roaf 124). Also, 1,200 years before Pythagoras, the Babylonians were familiar with the basic ratios of the sides of a right triangle. Saggs cites tables of calculations, correct to three or four decimal places when converted to our terminology, listing numbers linking the length of one side in relation to the lengths of the other two sides (Saggs, Civilization 225-226). We have little or no knowledge as to how these recipes were developed, but they had practical use, were computationally sound, and gave correct answers (McClellan 50). For example, lists of coefficients were used to determine the carry loads of certain building materials. Coefficients for precious metals were used in trade. Akkadian problem texts covered topics such as solutions of linear and quadratic equations, and computing the areas and volumes of different geometric figures that were applied to the construction of canals (Roaf 124). Archaeologist C. Leonard Woolley describes how they were able to apply geometry to calculate the area of a plot of land of irregular shape.[23] Linear equations were solved to determine shares of inheritance and the division of fields. The texts also boast of teaching scribes to balance accounts, make pay allotments, and manage many forms of administrative accounting. Babylonian mathematicians calculated exponential functions, seemingly abstract, but actually used to calculate compound interest (Oppenheim 306-307). These problems were generally solved in a recipe-like fashion, with little or no abstract understanding of numbers.

So, how did Mesopotamian mathematics compare with its contemporaries and subsequent systems? Like the Mesopotamians, the Egyptians of 3,500 BC to about 1,700 BC used a symbolic hieroglyphic number system. The symbols were combined to form intermediate numbers and formed a base-10 system that was not positional (Kline 19). Egyptian numbers operated like later Roman numerals, with separate signs for the decimal numbers and no place value. The Egyptian system was essentially additive but they used a method of duplication, an approach of multiplication by doubling and redoubling numbers, that worked with a Roman-style number system (Kline 19). They also arrived at a superior calculation of pi, 256/81 or 3.16, compared to the rough value of 3 found in Babylonian mathematics, and developed tables that facilitated working with fractions (McClellan 49-51). In general, the Egyptian system was more cumbersome than the Mesopotamian system and less efficient in handling advanced calculating

[23] By squaring it off, so that the total of the complete squares summed to that of the right-angled triangles, which fill in its contours, they arrived at a very good approximation (Woolley 110).

requirements (McClellan 49). The later Roman numeral system also had distinct disadvantages versus the Mesopotamian system in that every time the Romans multiplied by ten, they required a new signs such as X, C and M, that were ultimately limited by the number of letters in their alphabet (Hogben 39).

Like the river-based agricultural societies in Mesopotamia and Egypt, the Indian[24] and Chinese societies developed a bureaucratically practical system of applied mathematics. By the first unified empire under Chadragupta Maurya (321-291 BC) and his grandson, Asoka (272-232 BC), the elaborate Indian bureaucratic structure made use of mathematical recipes for practical concerns. Significantly, however, the Indian system developed into one that used nine Arabic numerals plus a zero.[25] The Indians were keen mathematical astronomers and were adept at measurement, algebra, trigonometry, negative numbers, irrational numbers, and the calculation of pi to four decimal places (McClellan 141-146). Examination of Chinese symbolic numerals indicated unique symbols for 1 through 10 and further symbols for powers of 10 (e.g., 100, 1000, …) that seem very similar to our modern Arabic numeral system (McClellan 130). They had a decimal place-value system by the 4th century BC, knew the Pythagorean Theorem by the 3rd century BC, and they used counting rods and the abacus to facilitate arithmetic operations by the 2nd century BC. The Chinese mastered large numbers using a base-10 system, handled squares, cubes, and, like the Babylonians, solved problems by what we today would call quadratic equations. Though by the early current era's seemingly playful exploration of numbers by Zu Chougzhi (429-500 AD), who calculated pi to seven decimal places, Chinese problem texts principally dealt with practical measurements of agricultural fields, cereal exchange rates, construction, and distribution problems (McClellan 130-131).

It is clear that the development and evolution of advanced mathematics by the priestly classes and the practical applications by the scribes of Mesopotamia existed long before the Greeks and has had a considerable influence on a number of societies, including our own. As Hogben notes, "There is no doubt that the raw materials of Greek mathematics were imports." He also cites the influence of the Phoenicians of the Levant on the Greek colony of Miletus, on the father of Greek geometry, Thales of Miletus (640-546 BC), and their influence on the travels of Pythagoras in Egypt and Mesopotamia (Hogben 60-61). One might also surmise that Alexander's conquests of Persia and India provided ample opportunity for his teacher, Aristotle, to "borrow" the works of Babylonian, Persian, and Indian scholars to further expand and refine Greek philosophy into a rigorous scientific method.

Some science historians argue for purely practical applications of Mesopotamian mathematics. According to McClellan and Dorn,

> "In most historical situations prior to the 20 Century, science and technology have progressed in either partial of full isolation from each other – both intellectually and sociologically" (McClellan 2). "Since higher learning was heavily skewed toward useful knowledge and its applications, in this sociological sense applied science, in fact, preceded pure science or abstract theoretical research later fostered by the Greeks" (McClellan 46). The Mesopotamians recorded knowledge in lists, "rather than in any

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[24] Civilization arose along the Indus River Valley in the 3rd millennium BC, but declined after 1800 BC into tribally organized agricultural communities. Under the Brahmin priestly class, the Sanskrit language was codified by the 6th century BC. Subsequent invasions of India by the Persians in the 6th century BC and their occupation of India for 200 years, plus 4th century BC invasions by Alexander the Great, opened the doors to Persian and Greek influences, which had been influenced by Mesopotamia.

[25] Indian religious and philosophical notions of "nothingness" may have contributed to the appearance of zero in Indian mathematics (McClellan 146).

> analytical system of theorems or generalizations…[and pursued it with] a notable lack of abstraction or generality and without any of the naturalistic theory or goal of knowledge as an end in its own right that the Greeks later emphasized" (McClellan 47).

The University of Chicago's renowned Assyriologist A. Leo Oppenheim also notes that, "They convey the procedure as such without the elaboration of the numerical results, using measurements and other given numbers solely to illustrate the operations described" (Oppenheim 307).

Abstract thinking, our precursor to science, rose from the Mesopotamian practicalities of applied engineering and mathematical astronomy, plus a bit of divination as the bridge to abstract thinking. The remarkably accurate astronomical data, accumulated over many centuries without the telescope or any form of chronometer, is a lasting memorial to the capabilities of the Mesopotamians (Derry 13). They had tables that determined the first and last visibility and the beginning and end of retrograde motion of the planets Venus, Mercury, Saturn, Jupiter, and Mars (Saggs, Civilization 239). They determined the exact times and positions of the new moon and full moon. Saggs, notes that, "The Babylonians concerned were employing a sophisticated mathematical astronomy relating planetary and lunar motion which was not surpassed until the coming of Copernicus" (Saggs, Civilization 239). Even McClellan and Dorn give them credit for using systematic research to solve specific problems in astronomy, such as whether the month has 29 or 30 days, and cite this as theoretical, "…insofar as more attention was paid to the abstract models of mathematical cycles than to what was visibly going on in the heavens" (McClellan 52-53).

Since the rulers of the region considered themselves to be agents of the gods whose duties therefore included performance of rituals and ceremonies to ward off evil and gain the good graces of the gods, by the 2nd millennium BC, the kings commanded that omens correlated to celestial phenomena be observed and recorded (Roaf 74). By the 1st millennium, the "science" of astrology became very important. Continuous observations date from 747 BC. Signs of the zodiac were named and by 500 BC the Babylonians could predict the movements of the moon and the occurrence of eclipses, solstices, equinoxes, and the cycles of the sun and the moon. They could also predict the movement of heavenly bodies indefinitely into the future (McClellan 52). From 410 BC to 75 AD, horoscopes and almanacs predicting the positions of the sun, moon, planets, and stars were compiled (Roaf 124). According to Roaf, "…the practice of first recording observations and then applying accepted theories in order to predict the outcome is the basis of modern scientific method" (Roaf 124).

The French Assyriologist Jean Bottero argues in favor of abstract Mesopotamian thought. Since the ancient Mesopotamians considered every aspect of the material universe as appropriate subjects of study for the purpose of extracting the plans of the gods, a deductive form of divination can be inferred from the writings found in texts such as *The Great Treatise on Astrology*.[26] Divination was originally empirical, based on a simple set of observations of historical events that the Mesopotamians thought would repeat itself. These unusual events, and similar appearances, were grouped and were "multiplied in the eyes of the people who believed in them," notes Bottero. The first phenomenon would signal the second, and the two together were recorded as an oracle of universal value. To our modern sensibilities this would seem extremely superstitious, however, to the Mesopotamians, this allowed the practitioners to expect

[26] The objects whose appearance was considered to be ominous required the study of: stars, meteorites, weather, waterways, vegetal elements, birth, animal internals, and the conscious and sleeping lives of people (Bottero 127).

to see a repetition of an analogous event in the destiny of the king or the land, whenever the anomaly was noticed again (Bottero 131). As the practice became institutionalized, Bottero believes that the Mesopotamians' desire to analyze and systematize their observations led to a deductive reasoning that went beyond the observed reality into the realm of the possible. "Mesopotamian divination attempted to study its subject as universal, and in a certain sense *in abstracto*, which is also one of the characteristics of scientific knowledge," explains Bottero (Bottero 127-135). He drives the point further, especially as divination was increasingly linked to mathematical astronomy:

> "From a knowledge based on pure observation *a posteriori*, starting from individual cases that were fortuitous and unforeseeable, divination became thus *a-priori* knowledge,...before the end of the third millennium at least. That knowledge was deductive, systematic, capable of foreseeing, and had a necessary, universal and, in its own way, abstract object, and even had its own manuals. That is what we call a science, in the proper and formal sense of the word" (Bottero 136).

Bottero argues that, "... the Greeks did not develop their conceptions of science, which we inherited, out of nothing; in this important point, as well as in others, they owe a debt to the ancient Mesopotamians." What may have passed on to the Greeks, according to Bottero, was this "scientific point of view, scientific treatment, and the scientific spirit" (Bottero 125).

The roots of modern western scientific inquiry can be traced back to the classical philosophies of the Greeks, who were influenced by Phoenician,[27] Egyptian, and Mesopotamian scholars. As Woolley noted,

> "We have outgrown the phase when all the arts were traced to Greece and Greece was thought to have sprung, like Pallas, full-grown from the brain of the Olympian Zeus; we have learnt how the flower of genius drew its sap from Lydians and Hittites, from Phoenicia and Crete, from Babylon and Egypt. But at the roots go farther back: behind all lies Sumer" (Wooley 194).

Hogben argues that ,

> "The veneration of the Greeks by their successors is indeed due to the fact that they were the first to insist explicitly on the need for proof." Though Greek mathematics were imports, "...they had to pass the customs of Greek incredulity," among a society partial to dispute resolution and competition among rival teachers (Hogben 60-61).

So, it is not that the Greeks monopolized abstract thinking; they refined it.[28] Ionian Greek philosophy and its classical definitions of truth and beauty, exemplified by the Socratic logic of Plato, and the later Hellenic-era metaphysics of Aristotle, laid the foundation for rational scientific inquiry[29]. Plato believed that truth emerged through the power of reason and we

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[27] See Gionanni Garnini's analysis of the history of the Phoenician alphabet and its adaptations by the Greeks in <u>The Phoenicians</u> edited by Sabatinoi Moscoti (Moscati 101-119).

[28] Thales of Miletus, Anaximander, Pythagoras, Socrates, and Plato developed many of their ideas using earlier ancient works as their base (Goldstein 48-64).

[29] The Ionian Greeks had an earthy tradition that stressed the enjoyment of life, commercial property, aesthetic refinement, and acceptance of newcomers. This allowed free thought and inquiry to flourish. From its earliest manifestations, the Greek mind had turned to natural philosophy, which was indistinguishable from Greek scienc e. Led by Thales of Miletus, the Greeks saw the formation of the earth by natural processes, no longer through an act of the gods. "The Ionians conceived of nature as a completely self motivating entity," according to science historian, Thomas Goldstein. The

observe truth as making sense. Aristotle, the son of a physician and Plato's pupil of twenty years, took his master's basic philosophy, added more structure and advocated verification of intuitive natural laws with objective observation (Loomis vii-xiii). Both a great thinker and a great scientist, Aristotle set the tone for future scientists by his method of inquiry and an avowed determination to yield to observation as the final arbiter.[30] As a result, an atmosphere of sober empiricism distinguished the Hellenic Greeks from the Ionians, with Aristotle being credited as being a great dividing line in Greek history. Aristotle's pupils and their successors carried on his teachings at the *Lyceum* for over 800 years, until, like Plato's *Academy*, it was closed by order of a Christian emperor in Constantinople (Loomis X). [ii]

Greek science, by the sheer process of speculation, argument, intuition, plus a dash of empirical reasoning, had moved, within the space of two generations, from the early mythical notions to a point that is surprisingly close to modern concepts (Goldstein 52). Having channeled the power of Greek philosophical thought into a logical system of scientific classification, Aristotle came to exercise an enormous influence over European science for the next two thousand years (Loomis, xi-xxxviii). When Europe awakened from the feudal Dark Ages and the Medieval suffocation of theocracy to an enlightened approach to knowledge that included the works of Francis Bacon, Sir Isaac Newton, and Nicolaus Copernicus, it embraced the process of observation, generalization, explanation, and prediction that was fully rooted in an earthy materialism, indicative of the age.[iii] This view of knowledge became pervasive, changing assumptions not only in science but also in the entire social fabric of Europe. Europe came to understand that the physical realm of nature is real, orderly, and, in part, understandable.

Though one might argue for the theoretical neutrality of science as pure abstract knowledge, it is clear that *technology* or *technique*, upon which *science* is built, is never neutral. From its earliest uses in the advanced civilizations of Mesopotamia, Egypt, India, China, Greece, Rome, and Mesoamerica, through its applications by Medieval Arabs and Europeans, through its acceleration from scientific developments of the Renaissance, Industrial Age, and the modern Information Age, technology has been the servant of human needs, desires, intents, and actions. Technology's potential to address human needs and motivations is a function of the state of earlier technologies accelerated by the sum of a civilization's social values, which are in turn functions of society's *worldview*. What we know, i.e., *scientific knowledge*, and what we don't know but try to explain, i.e., *belief systems* form the worldview. As ancient Mesopotamia shows us, the technology of record keeping, and especially what society does with these techniques, is a matter

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workings of the universe occurred as mere extensions of the primordial chaos, automatic functions of its basic elements. Matter possessed its own evolutionary quality. 'Order' and 'law' were mere concepts superimposed by the human mind on the autonomous processes of nature. It was Pythagoras who is credited with the introduction of the vision of an intrinsic natural order and Plato adopted this vision (Goldstein 52).

[30] Unlike Plato, Aristotle did not believe in a world of ephemeral appearances of changeless ideas. Loomis notes that Aristotle argued that, "…the world really is, has been, and will continue to be, regardless of human eyes and imaginings" (Loomis xvii-xviii). However, like Plato, Aristotle thought it necessary to, first of all, understand and explain the workings of the human mind and to show what kinds of reasoning were valid and could be relied upon to provide knowledge with surety. In his *Organon*, Aristotle made clear the processes of logical, reasoned thinking and for proving the correctness of its conclusions. He made plain the steps by which a science or body of knowledge may be firmly built up from its starting point in certain fundamental axioms or obvious statements, perceived intuitively to be true. Every science, as Aristotle pointed out, must begin with a few general truths. They cannot be logically proved, but our minds by simple intuition accept them as obviously true. Without such assumptions as foundations, we could never start to build anything (Loomis, xi-xxxviii). Louise Loomis, editor of a 1940's translation of Aristotle's *Metaphysics*, noted that he reasoned like Plato, from ideal abstract principles, whenever the subject of the reasoning lay outside his field of observation.

of cultural values and societal choice. Traditionally, technology as a trial-and-error art is thought to have developed separately from science as an abstract discipline throughout most of recorded history. As seen in Mesopotamia, the practical techniques of arithmetic and geometry can be used for construction and commerce, and they can be combined with astronomical observation to produce calendars, almanacs, and the determination of ideal planting cycles. In this sense, it can be sometimes viewed as *applied science*. Yet, from the ancient Sumerians until modern times, much of *technique* continues to be developed with little or no basic scientific knowledge. As McClellan and Dorn cite, "…in many instances technology directed the development of science, rather than the other way around" (McClellan 2). One can certainly see the links in the case of Mesopotamia, where accounting techniques led to a mathematical system, which when combined with the observational impetus provided by religion, led to prediction and then codification into general rules that were precursors to science.

Oppenheim stresses,

> "The Mesopotamians have a right to be proud of their accomplishments." Their use of "sophisticated mathematical tools of ingenious simplicity" demonstrates how the administrative and utilitarian mathematics developed to that of a vehicle of scientific creativity. "Their mathematical methods can well stand comparison with the accomplishment of all other civilizations up to the middle of the second millennium AD, i.e., for more than three thousand years" (Oppenheim 306).

If one accepts this as true, then by extrapolation, modern society's scientific method owes its birth to the mathematical foundations of ancient Mesopotamian engineering and the subsequent abstract thinking that its culture fostered.

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Notes

[i] BBC reporter and author of Connections, James Burke, presented a good summary of the ways in which technologists experience the effects of economics and human values. Burke designates six major initiators of technical innovation. They are: deliberate invention, accidents, spin-offs, war, religion, and the environment.

First, as one might expect, technical innovation occurs as a result of deliberate attempts to develop it. When inventors like Lewis Howard Latimer and Thomas Edison began work on the incandescent bulb, it was done in response to the inadequacy of the arc light. All the means were available: a vacuum pump to evacuate the bulb, electric current, the filament which the arc light used, and carbon for the filament. With these components the remainder of the required work was the synthesis of technologies toward a definite goal --the light bulb's creation.

A second factor that frequently occurs is that an attempt to find one thing leads to the discovery of another. For example, William Perkin, searching for an artificial form of quinine, used some of the molecular combinations available in coal tar and accidentally found that the black sludge produced by one of his experiments turned out to be the first artificial aniline dye.

Unrelated developments have decisive effects on the primary event. An example of such spin-off developments can be seen by the development of paper. The medieval textile revolution, which was based upon the use of the spinning wheel and the horizontal loom, lowered the price of linen to the point where enough of it became available in rag form to revolutionize the paper industry. Burke discusses other examples of how unforeseen circumstances play a leading role in technical innovation. This includes the stimulation of mining activities for metals to make cannons when Chinese gunpowder was exported to Europe and the development of a barometer as a result of frequent flooding of mines and the failure of pumps.

The fourth and fifth factors are all too familiar: war and religion. The need to find more effective means of defense (or offense) has driven technology from the most ancient of times. The use of the cannon led to defensive architectural developments that made use of astronomical instruments. As previously discussed, ancient Mesopotamian, Egyptian and Mesoamerican religious beliefs led to great strides in engineering and architecture and the Islamic world fostered advanced astronomy because of the need to pray, feast and fast at specific times.

Finally, physical and climatic conditions play important roles. For example, the extreme changes in Europe's winters in the 12th and 13th centuries provided urgent need for more efficient heating. The chimney filled the need and had a profound effect on the cultural life of that continent.

[ii] The classic Roman civilization built upon Greek science to develop their mighty empire with its renowned technical prowess. The Romans, being driven by conquest, glory, commerce, and an increasing need to find new resources never really flowered as scientists. Free thought was not the hallmark of Rome. The Roman way of doing things was impressed upon its citizens and conquered states as a matter of standard procedure. The Romans did, however, undertake massive engineering feats such as extended roads, aqueducts and highly structured cities (DeCamp 172-280). Here technology flourished but no new ideas of philosophical importance stand out. Great translators of other works, the Romans were exploiters of resources and fantastic implementers of technology. As Rome crumbled under the weight of countless invasions, the cosmic vision of the Greeks and the technological achievements of the Romans shriveled. With Europe over-run by the Germanic tribes, scientific inquiry was stunted for a millennium. Europe slept in a stupor of ignorance for one thousand years. "To those who lived through the catastrophe, it seemed that the utter breakdown of civilization had come, the ruin of everything humanity had ever tried to create over thousands of years, a verdict from a wrathful heaven," according to Goldstein (Goldstein 55). Europe

reacted with a radical readjustment of mind, turning their backs on the world of the senses, which now seemed unworthy of intellectual scrutiny. The end of Roman civilization meant a steadfast attachment by Europeans to the dogma of Christianity. To Europeans it offered the only hope left.

When the hope given by the Church was no longer needed, new morals and money provided the impetus for Europeans to cast the Church aside in favor of a new age -- the Renaissance. Suddenly, being earthy and gauche was in. Once again Europe entered an age of free inquiry, but this time a novel twist accompanied the new age. The new twist was represented by a view of life advocated by a new breed of wealthy philosopher/scientist.

The European Scientific Revolution of the 16th and 17th Centuries began with Nicolaus Copernicas who overthrew the geocentric view of Ptolemy and The Bible that had been accepted for over a thousand years. After Copernicus, the earth was no longer the center of the universe but merely one of the many planets that circled a minor star in an insignificant galaxy. Radical in its impact, this view of the world robbed humans of their proud position in the center of God's creation. Without dogmatic theological constraints, other scientists such as Johannes Kepler who is credited with the laws of planetary motion, Galileo Galilei the re-discoverer of many of the principles of gravitation and the invention of the telescope, and sir Isaac Newton who combined much of his previous work into the laws of motion each contributed to the Renaissance's spirit of inquiry.

[iii] Two aspects of these scientists' work stand as foundations of modern science. They include the empirical approach based upon objective, rational observation, and the use of mathematics to describe nature. The two criteria for the dynamic entity of scientific truth, either one of which is generally sufficient to cause persons to accept a principle, are first, that it can be checked by observation in a manner in which its consequences lead to its support rather than to contradictions; and second, it can be derived from intelligible principles (Fischer, 49). These principles laid the groundwork for modern scientific methods of inquiry and were forcefully argued by Rene' Descartes, the philosopher, and Francis Bacon, the theologian (Capra 15-120). This new approach also included the process of generalization, explanation, and prediction, or what can be thought of in modern terms as the *hypothesis*, *theory*, and *law*.

A *hypothesis* is a tentative assumption made in order to test its scientific consequences, but which as yet has received little verification or confirmation. A *theory* is a plausible, scientifically acceptable statement of a general principle and is used to explain phenomena. A *law* is a statement of an orderliness or interrelationship of phenomena that, as far as is known, is invariable under the stated conditions (Fischer 47). It should be stressed that the term law is used differently in reference to scientific knowledge than to other areas of everyday life. A scientific law is descriptive rather than prescriptive. It is a statement used to describe regularities found in nature, and is not a statement of what should happen. It is not correct to consider that natural objects obey the laws of nature; rather, the laws of nature describe the observed behavior of natural objects. In contrast, the laws of a human government are prescriptive in that they prescribe how people should behave.

Another guiding principle of science is its supranationality -- its inherent right to transcend national boundaries and allow scientists throughout the world to verify experimental results, challenge, theories, and allow technology to leverage new scientific discoveries.