Evolution of science I: evolution of mind

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The central nervous system and particularly the brain was designed to control the life cycle of a living being. With increasing size and sophistication, in mammals, the brain became capable of exercising significant control over life. In Homo sapiens the brain became significantly powerful and capable of comprehension beyond survival needs with visualization, formal thought and long-term memory. Here, we trace the rise of the power of the brains of the Homo sapiens and its capability to comprehend the three spatial dimensions as well as time. By tracing the evolution of technology over the last millennium and particularly the late arrival of astronomy, evolution of the formal thinking process in humans will be discussed in a follow up paper. We will trace the extensive use of this new faculty by humans to comprehend the working of the universe.

Keywords: Astronomy and comprehension, evolution of mind, evolution of thought, human intelligence, primate and human brain.

LIFE exists in an environment where its primary purpose is to eat, not be eaten and to reproduce. In this eternal race for survival, size gives an obvious advantage. Dinosaurs took this idea to the extreme, building increasingly larger bodies. Eventually they became so large that they were incapable of adaptation and perished in a natural catastrophe.

The next best strategy was to make medium-sized life forms that were more capable of adapting to different environments thus improving their chances of survival[1]. This kind of formal adaptability was best served by a nervous system that was capable of understanding environment and responding to it in a complex manner to improve the survival chances of life forms. Such a nervous system required a flexible brain that needed to operate in a stable environment within the body of the life form. Due to the nature of biochemistry, such a brain has to work in a constant temperature environment. The optimum temperature for the working of the brain chemistry was slightly higher than the ambient temperature of the Earth in most environments. A series of adaptations eventually created warm blooded animals that could maintain a warm body and brain. These animals are classified as mammals and, in most cases, incubate their young ones inside their body to ensure that the brains of the young one grow well under the mother's warmth. They also look after the young during their early period after birth since these complex brains require post-birth training to efficiently exploit their environment. While the earliest mammals existed during the time of dinosaurs[2], their room for evolution was heavily constrained by the giants on the ground.

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Mammals flourished and became the most aggressive and dominant species on the earth only after the disappearance of dinosaurs. We ignore the insects here since they ensure their survival more by group activity and a different response to the challenge of survival. The competition for increased adaptability was met through increased intelligence and more streamlined bodies. It eventually reached a stage where the homo series of animals, with the most efficient combination of body weight, adaptable body and a well-structured brain appeared on earth. This particular group of mammals had the highest brain to body ratio and ended up with intelligence in excess of what was needed for controlling the body and managing the immediate environment. They also had a versatile body form that permitted them to not only adapt better, but also undertake systematic manipulation of their environment.

The mammals with the highest brain-to-body ratio, the *Homo sapiens* appeared on earth about two million years ago and then further transformed into Homo Sapien sapiens about six hundred thousand years ago[3,4]. The current body form that we call Homo Sapien sapiens, at their peak, had a brain about 1500 cm^3 in volume, about 20,000 years ago. It seems to have been trimmed by nature to a more optimum size of 1350 cm^3 (about 10% reduction) at present, apparently to optimize its function by optimizing its design[5].

Evolution of human understanding of nature

Human studies of nature and its manipulation go back to about two million years probably with sticks and stones to acquire food. However, even the early *Homo sapiens* – the archaic humans – already had enough surplus computing power in their brains to go beyond simple adaptation to aggressive exploration of nature. Several early discoveries and inventions were made by archaic humans. These include flaked tools and hunting technologies[6] and evidence of group hunting using spears 1.3 million years ago in Africa[7] and three hundred thousand years ago in Europe[8]. They also spread over several parts of the earth. About 600,000 years ago one such group produced a variant with the highest brain to body ratio, firmly biped and a fast paced brain. These are the Homo Sapien sapiens. However, getting a perfect tuning of brain and body took a long time and adjusting various body parameters, including, for example, evolving vocal chords that could produce a large variety of complex sounds, came only about fifty thousand years ago[5]. These are generally called behaviourally modern humans. But even before reaching this stage, humans had already invented jewellery about 135,000 years ago[9]; had learnt to control fire 300,000 years ago[10] and probably had a formal language by a 100,000 years ago[11]. The oldest art on red ochre can be dated back to 100,000 years[12] with marked terracotta pieces going back to about 17,000 years[13]. The oldest human bed made with twigs dates back to about 77,000 years[14]. They had begun to spread all over the globe by moving out of Africa about a 100,000 years ago[15]. Here they would meet other archaic humans and were capable of mating with them. There seem to have been at least two points in Europe and East Asia where they seem to have interbred[16]. Figure 1 gives a brief timeline of various discoveries and inventions by humans.

Growth in human understanding of the environment

This progress was a result of significant developments in human comprehension of the universe. This is shown in Figure 2 (ref. 17) where we quantify various aspects of human intelligence and environmental impact to study how the different faculties of human mind evolved with time. Here we use ‘mind’ to imply a mix of the hardware of the brain and the intellect that works with it.

We begin with the minds of the great apes and study the evolution of the complexity in the perception with time (Figure 2). Several studies have shown the subtle, but important differences between the minds of the great apes and humans, even as infants and children[18]. Similarly, studies[19–21] have considered the evolution of the *Homo sapiens* and early human minds from the perspective of growth and evolution of comprehension and early expressions of art. Based on these studies, it is clear that the world of the great apes is instinctive and they have only a weak concept of acquired knowledge or systematic collaboration of collation of knowledge over time. Here we extend these ideas to gauge specific aspects of evolution of the human brain. We divide the growth of human intellect from the period of great apes to humans in the following sequence.

In the natural environment, there are three forms of intelligence, namely physical intelligence, sensory intelligence and response to environmental stimuli. Physical intelligence in turn has two components, the biological and mechanical intelligence that is associated with the animate and inanimate world respectively. For this purpose, the body has various sensory inputs that give the brain sensory intelligence consisting of visual and auditory intelligence, etc. whereby it interprets the signals it receives. These arise from the stimuli it receives from the environment through its five senses. We distinguish between sensory intelligence and environmental stimuli in the sense that senses may exist and can work purely instinctively or may be interpreted to derive additional inferences. This requires an additional intelligence to interpret the signals conveyed by the senses received from environmental stimuli.

With time, better organization of the brain occurs. These acquire different features and the resultant intelligence can be divided into multiple components. It then derives a certain understanding about the physical world. In view of the nature of life, visual signals take up maximum brain power and have the highest priority followed by auditory signals. The sense of touch, taste and smell is primarily used for acquiring and processing the food. We classify it as biological intelligence that deals with a variety of information. It becomes aware of body and response of the body to different stimuli, learns of manipulation of food for improving body response and use of plants for medicinal purpose, appreciates its body response and becomes sensitive to exhaustion, and illness. In humans and even in chimpanzees this results in becoming sensitive to the medical benefits of plants etc.[22].

Mechanical intelligence arises from observing the properties of matter and manipulating them for tool making.

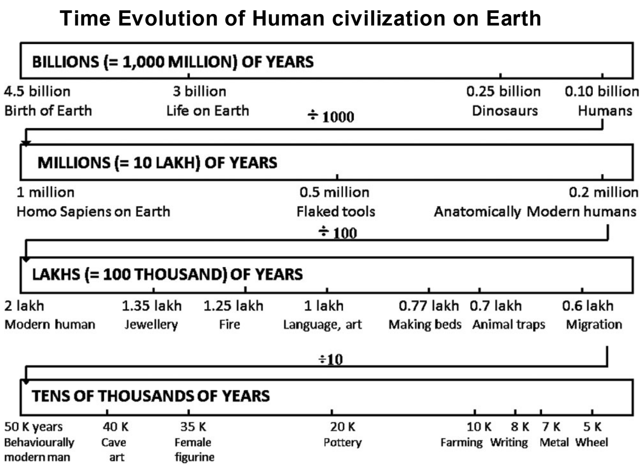

Figure 1. Landmarks in development of technologies by humans.

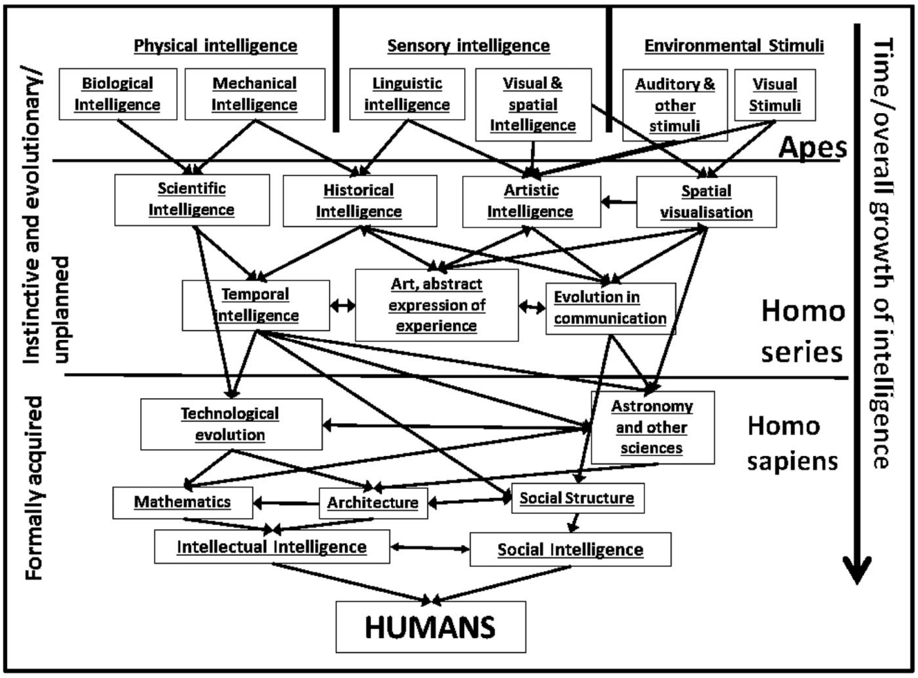

Figure 2. Evolution of human intelligence with time.

The capacity to make controlled sounds and their recognition brings in linguistic intelligence where recognition of sound as an indication of occurrence of an unusual event including threats and treats is crucial. The auditory and olfactory senses sensitize the brain to inputs from sounds arising from animal movement and other natural phenomena, environmental stimuli as well as inter-community and intra-community signals. The inputs from touch and taste, in turn, allow sensitization of the environment and provide the capability to understand the immediate environment and its effects on the body. The visual and spatial intelligence provides a map of the environment and perception of motion and information on static environment, dynamic environment, signals from the environment in terms of sensitivity to the time of day, recognition of local landmarks. It can also invite hallucinatory stimuli with visualization of abstract images. Lastly, when this information is processed by the brain in the sleep mode, it results in dreams.

We share most of these features with other primates and even lower animals. However, their complexity and sophistication vary. As the size of the brain and its internal organization improves, the brain makes a transition from instinctive and evolutionary or unplanned working, to a more formal acquisition of knowledge. This acquisition of social identity, altruism and collaborative aspects seem to be pre-programmed in the human brain[18]. Based on these stimuli, human brains with higher complexity and computing power will develop a whole series of complex intelligences. This will include an instinctive perception of the working of the environment that we call scientific intelligence which includes comprehension of the rules of nature, evolution concept of medical plants and repair procedure. The brain will also develop historical intelligence based on memory of past experiences. This will include comprehension from visual and other direct signals from predator/prey, recall of past experiences, recall of local geography and recall of common experience of the group through common experience.

Humans are also capable of several biological and mental gymnastics. These include use of opposable fingers to hold and manipulate objects, complex vocal chords to produce a large variety of sounds, a brain that can not only comprehend and store information, but can also extrapolate to understand and anticipate actions of others based on minimal signals. Similarly, being biped gave humans a longer reach and upper limbs to dedicate to activities beyond locomotion. Together, they give the humans a complex ability to be expressive beyond their survival needs. They can comprehend the working of nature and develop artistic intelligence to express themselves. This included comprehension of visual or auditory signals and reproduction complex of auditory signals and its subsequent analysis that allows humans to create a complex worldview that spanned long timescales. They can go beyond this through abstraction of visual signals and reproduce these visual signals through representative and performing arts. Under the correct conditions they can also hallucinate, go into trance and experience surrealistic experiences. By the same token, they can also experience love and a sense of loss and grief at the loss of that love, be it for another human or an environment.

Together, this set of capabilities gives humans a strong sense of power and a desire as well as capability to manipulate their environment.

We have also paid a heavy evolutionary price for this. The physical development of a young human takes much longer than that of other animals. This has been attributed to the excessive metabolic demands of the brain, which seems to suck away a large fraction of resource from human infants in the early years[23]. We also sustain a biped body that is clearly not fully efficient. The very fact that we need to change postures – sitting, sleeping horizontally – suggests that muscle development and support system for the unstable equilibrium of biped style have not been fully balanced by our large flat feet and strong leg muscles which are reasonably adequate, but are unable to sustain a standing posture over long periods of time. In other ways also, the brain extracts a huge fraction of resources from the body[17].

With increasing time of evolution, two more features become apparent. The first, the complex temporal intelligence includes understanding of long term variation, as well as time-dependant changes, understanding temporal-spatial consequences of movement, a sense of events that occur over extended time scale and even notice their periodicity. With accumulation of historical information, they even develop understanding of events over much larger time scales of human lifetime and beyond. Evolution in communication would lead to the development of language and recognition of emotions in animate sounds.

Being social animals, they also develop a complex work view, which includes a sense of evolution of time on different time scales to a visualization of partially visible objects in static and dynamic environment through conscious and learned visualization. With memory they can also identify periodic and aperiodic events. It also forces them to create a series of *ad hoc* models to classify their information and convert it into a framework against which they keep track of the massive information and prevent overload of raw data. As intelligence evolves, this becomes increasingly more sophisticated and complex. These frameworks can include both mythos and lagos – the mythological and logical models to help them understand and predict the events in life. They can even create a mental image of the thought process of another being beyond immediate threat perception through what is called the Theory of Mind[24.25].

These features were probably common even before the modern humans – the *Homo sapiens* – arrived on the earth. As a result of this complex evolution of human brain size and consequent improvement in computational capabilities, human mind would evolve even further in the form of technological evolution, namely, ability to manipulate environment and physical properties of material, creation of complex devices for efficient machines, manipulation of material property and modification of mechanical objects for specific purpose.

Such a learning would be backed up by a certain amount of social evolution and interactions including idea of self and perception of other individual's mind, development of collaboration and supportive altruism. They would also create myths and religions to try and give some form of explanation to the cause of the events around them. They would eventually create formal art and writing and recall from acquired knowledge, largely through language.

As a result of these developments, humans acquire a four-dimensional world view – three of space and one of time. The realization of the third dimension of space would introduce them to astronomy. This would open a completely new set of intellectual challenges from predicting seasons and calendar and a sense of vast sky that they would try and comprehend based on their world view[26].

The final evolutionary trait would recognize the two modern classifications of human intelligence. This would involve what we call intellectual intelligence. This would include, intelligence of taste – nutrition relation, intelligence to handle multi nodal inputs from different intelligences, specific search for information from a particular region. This in turn would provide them with an ability to mix comprehension and acquired experience, an ability to control instinct, and involuntary action to perform unusual functions such as fainting as a defensive mechanism. Such a brain would be able to handle multi-nodal cross talk between senses and memory. It would also have a formal understanding of arithmetic and number system including formal capability of mathematical problem solving. The result would be an integrated understanding of physical sciences (physics, chemistry, etc. as well as mathematics). The brain would be in a position to comprehend artificial signals, their visualization and reality altering experiences, such as those experienced from music and art. It would also be capable of creating complex devices for efficient machines and manipulation of material property to create instruments such as animal traps and custom designed weapons and tools for individual needs and train younger generation to use this acquired knowledge that can significantly enhance human capabilities. The result would be complex interplay of developed technology which further increases understanding. The expanding capability would also be visible in abstraction and imaginative estimation of time and space evolved events and an informal recall of acquired knowledge largely through language and history with a sense of very long time scales beyond human existence.

Social intelligence would lead to development of features like humour with all its complexities[27]. A sense of ethics, right and wrong and evaluation of consequences of preconceived action would result in evolution of social norms. Concepts of property and ownership would create its own sense of identity and community. In terms of common memory, myths and religion would become formalized.

Expressions of thought would result in formal art and complex linguistic structures and grammar. Speculations on human relation to the environment would give the first philosophy and eventually writing would arrive as an aid to memory and then take its own separate path as a medium of self-expression. Ideas of history and philosophy would evolve. That cultural diversity and behavioural traits including choice of phonetics in a language (see below), is closely related the genetic polymorphism. This is well documented[28–30].

The interrelations between them (highlighted in Figure 2) show some interesting consequences. In particular, for subjects such as astronomy to evolve, it is important that not only are the visual stimuli understood and analysed in terms of their complexity, but the fact that they vary with time also need to be understood, before humans could appreciate astronomy. This can be seen from the plotting of points to indicate stars have been recorded in Lexus caves about 15,000 years ago. In reality astronomical drawings are rare and astronomically aligned structures arise only around 3000 BC and earlier megalithic structures and residing caves give no indications that humans looked and appreciated the sky.

Another aspect of this growth is the fact that there is no real increase in the brain size of *Homo sapiens* for the last 200,000 years and probably a small reduction in size but an increase in the level of sophistication of the connectivity within the brain, and an indication of the increasing complexity of brain's interconnectivity. The credit for this must go to the better organizing capability that our learner brain has. These changes in brain organization and its plasticity get transferred to later generations probably through genetic transfer indicating that the genes probably pre-decide many of the wirings in the brain at birth itself[28,30]. Hence, while some of the jumps such as rise in the idea of altruism[18], can be attributed to the larger brains with increasingly complex connectivity, rise of perception in the *Homo sapiens* and a natural adaptation must be attributed to acquired capabilities, which we refer to as the mind in further discussion. The fact that astronomy was not known to early *Homo sapiens*, with same brain size as ours, indicates that they lacked the sense of movement of time and evolution of the three-dimensional space the way we take as obvious. The fact that even young children below 1 year seem to be capable of this comprehension of time and space movement suggests that there must have been significant evolution of the genetic markers related to brain that ensured that even with the same brain size, its connectivity (or the mind) continued to improve. This raises important questions about the feedback loop between social evolution and genetics.

Feigenson and Halberda[31] have used 14 month-old infants whose brains are not filled with meta-memorial strategies and shown that they can use their memories with complex subdivision of pattern to be memorized indicating that the fundamental memory computation is available before the brain adapts to meta-memorial strategies. While Feigenson and Halberda[31] have used infant models, such studies have been used to understand time evolution of human brain capabilities. It is therefore well within the realm of possibility that after the *Homo sapiens* acquired their large brain, improvement of interconnections started before language acquisition and was accelerated with the arrival of language.

Also, while at least some of these developments seem to emerge at different locations nearly simultaneously, others were clearly local in origin[32]. The general nature of this evolution can be seen from the fact that even though humans moved out from Africa well over 100,000 years ago, all major steps of growth of human cultures such as farming, writing, urbanization, etc. arrived in different parts of the world around the same time even in diversely different environments and in a disconnected manner across several parts of the globe with similar compulsions. It appears that ideas seem to arise in a natural sequence of smoothly increasing sophistication of the mind. At the same time, there are many significant differences which can be attributed to factors such as the lack of a particular technological advancement. Others can be attributed due to some ideas not arising in a particular cultural group. These differences then mark the differences in different cultures.

All these improvements in the brain then give rise to a realization of the universe that is beyond senses, an independent entity and set of universal laws that are independent of the observer, the existence of a physical universe. The study of this universe is what we call 'Science'.

Rise in human comprehension and its impact on civilization: a case study of astronomy

The rise in human intelligence is related to the complexity in a circular manner. The more complex the culture, the more sophistication it demanded from the brain; the more sophisticated the brain became, the more it learned to automate the tasks and specialized itself, the more the society progressed. This progress of the society can be quantified in terms of various social parameters. This interplay has created truly complex organic cities where the interaction of individual intelligence, collective organization, automation and environment, have created a complex entity in its own right[33].

Astronomy generally begins with the belief in Mother Earth that needs to be seeded by Father Sky and the earliest image of a female with exaggerated femininity has been dated to 35,000 years[34]. These early ideas have then been developed to explain the role of Sun and Moon. Noting changing locations of the sunrise and sunset points and the seasons, the fact that the seasons seem to return more or less to the same phase over 12 Full or New

Moons, and the realization of static nature of star patterns is a large and complex development including development of technologies that have taken thousands of years. These include development of gnomons and sundials, megalithic horizon markers, constellation designs and associated developments of astronomical myths[26]. Hence, the recorded astronomical knowledge in each culture can be used to study its intellectual level. These growth of ideas can be quantified and studied as a function of other parameters of social sophistication. We use the period of stable settlement as a measure of sophistication of their living conditions and note their astronomical knowledge that has been derived from archaeological and other studies to understand the relation between social complexity and study of nature.

We use the knowledge of astronomy as the indicator of their intellectual sophistication. In Table 1 we list the period of settlement of various cultures and level of their knowledge of various aspects of astronomy. In Figure 3 we plot a graph of the time since settlement of a culture against the level of complexity as derived from Table 1.

This growth has not been without a certain cost to the culture in terms of manipulation of environment, loss of biodiversity, etc. But we shall not deal with these issues here.

Figure 3 demonstrates the relation between the period of settlement and the level of complexity. As can be seen from the figure, there is a clear correlation between the two across continents and cultures.

Development of society

Societies grow in a complex manner typically by inventing new technologies or ideas. These technologies and ideas take time to develop and do not grow to their full potential suddenly[35].

We present a simplified diagram of these complexities in Figure 4. Solid line in the figure shows the potential of a scientific or technological breakthrough while the dotted line shows the level to which the potential of the technology (or idea) is explored by a society. When

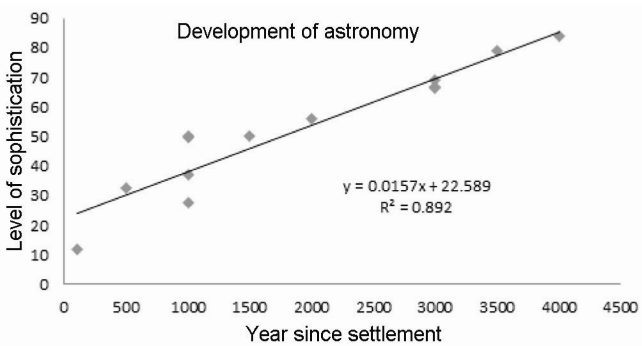

Figure 3. Growth of complexity of civilization with period of settlement (see Table 1 for the data).

the society reaches the level where the maximum advantage has been derived from a given technology, it needs to invent new technologies or new ways or organization in order to meet the increasing demands from the population for a better lifestyle.

While this stepwise increase in capabilities with time and the gradual rise in its exploitation can be traced back to the earliest history[35], recent history itself shows some obvious examples. The early history is conventionally classified as Stone Age, Bronze Age and Iron Age. The Iron Age itself lasted till the Second World War and it took us approximately 3500 years to fully exploit the iron technology. Beyond that it is safe to assume that we entered the silicon age with the advent of semiconductor technology. But we were far quicker in exploiting this technology and in about 60 years, we have seen its full exploitation. We are already beginning to see the saturation of this technology as we approach the end of the era where Moore's law was valid.

We are now probably entering the carbon age and it is impossible to predict how long it will take us to fully exploit this technology since carbon is a semiconductor and a versatile atom capable of making complex 4 atom structure and long chains that make it far more versatile than silicon whose only virtue is the control it provided on very small devices that could be manipulated by small changes in voltage. It is therefore useful to note that the age of carbon, does not imply an age of biology. While carbon is crucial to life and biology, carbon is far more versatile. With its intrinsic semiconductor property, its multiple forms from soot to diamond and its chemical versatility, it is one of the most flexible elements. Creating life giving molecules is just one of its many capabilities. The age of carbon therefore promises to be far more versatile and greater in reach than the age of silicon – which also has 4 valence bands, but is far too heavy and not as versatile a receptor as carbon.

This growth of humans from being one of the animals to the most dominant has been reached through a complex interplay of streamlined brains, systematic studies, and invention of recording techniques that allow us to hold on to past experiences and build on past achievements over long periods of time.

All this results in continuing studies of nature and environment, and in identifying the potentially exploitable technology for the large good of human beings. Curie and Mace[36] have shown that the success of an ethnolinguistic group depends on its political sophistication as derived from the complexity of the political order. Gelfand[37] has studied thirty three societies and showed that there is a significant variation in the cultural norms that can be classified as tight (have many strong norms and a low tolerance of deviant behaviour) or loose (have weak social norms and a high tolerance of deviant behaviour) and different societies respond differently to the same stimuli based on past history.

Table 1. Estimation of the complexity of astronomical ideas in different cultures and the estimated duration for which they have lived a settled life

Community	Period since settlement	Level of astronomy											
	Settlement when study is reported	Name for directions	Know constellations: <5 = 0.3; 5–10 = 0.6; >10 = 1	Astronomy in daily life	Myths of seasons	Philosophical myths	Astrology	Eclipses	Planets	Lunar mansions	Observatories	Cumulative score	References
Relative weight		1	10	5	8	10	10	10	10	10	10		
Gonds	1000	1	0.6	0.5	1	1						27.5	39
Kolams	500	1	0.6	0.5	1		0.5	1				32.5	40
Banjaras	100	1	0.3		1							12	40
Sumerians	3000	1	1	0.5	1	1	1	1	1		0.5	66.5	
Greeks	1000	1	0.3	0.5	1	1	1	1			0.5	49.5	
Chinese (early period)	3000	1	0.3	1	1	1	1	1	1	0.5	0.5	67	
Egyptians	1000	1	0.3	1	1	1	1					37	
Greko Roman	3000	1	1	1	1	1	1	1	1		0.5	69	Taken from Sumerians
Mayan	4000	1	1	1	1	1	1	1	1	1	1	84	
Rig Vedic	1500	1	0.6	1	1	1		1		1		50	41
Late Vedic	2000	1	1	1		1		1	1	1		56	42
India 500 AD	3500	1	1	1	1	1	1	1	1	1	0.5	79	43
Early UK	1000	1	0.6	1	1		1	1			1	50	

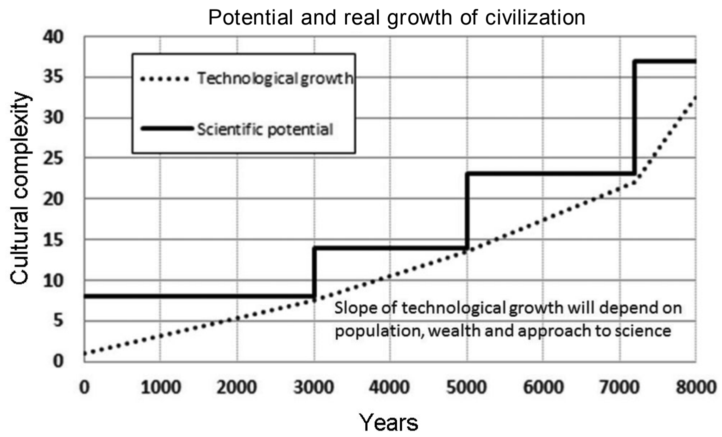

Figure 4. Growth of technological potential with time.

However, even within this broad scope, each individual society will respond differently based on three major factors, namely history, geography, and experiences as well as knowledge acquired in the past. Geography in particular will decide which resources a society will value the most, history will decide on its response to any specific stimulus. Under identical stimuli and faced with identical problems, different cultures will respond differently, even if two of the three parameters are similar. This is largely driven by the proximity of the people to any of the parameters and their sensitivity and recollection. History in particular is the most subjective of these parameters and the most influential. Probably the most dramatic response of the collective sense of need of a society is the response of the Soviet Union after the communist revolution, when challenged by the western neighbours with advanced science and technology forced them to adopt science at the cost of all else. They responded by banning religion and negating history. The rise of the Soviet Union as a scientific superpower was probably one of the shortest and the fastest rise of a civilization from one that barely tinkered with the dominant scientific cultures to a nation that could achieve all its dreams of power and dominance with its science and technology within the few decades. While, in principle, it is possible to make a similar statement about China's recent rise, there are several important differences. China has had a long tradition of science, and religion has not been an important drag on its thinking. Also, unlike the Soviet Union, China has risen initially by imitation and though it is a major economic power, its capabilities in pure sciences and long lead time vision based applied sciences is also limited. Its rise is primarily attributed to technology transfer and imitation.

Conclusions

The brain has evolved from a survival aid to powerful organ in *Homo sapiens* that can think and comprehend and understand the universe around it. This brain is capable of comprehending and analysing the universe. The growth has involved a complex play of experimentation and interaction as well as analysis of the environment as an independent entity that we call science. We will analyse the evolution of science in the accompanying paper[38].

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ACKNOWLEDGEMENTS. The author wishes to thank Sir Arnold Wolfendale for his continuing discussions and incisive questions which have helped clarify several aspects of the perspective presented here. He also wishes to thank Prof. Deepak Mathur whose careful reading of the manuscript and valuable inputs made the manuscript more exhaustive. We also wish to acknowledge the contribution of Mr V. Nandagopal in critically reading the manuscript. The author also wishes to thank Prof. Roddam Narasimha for several illuminating discussions during the course of the study. The author also wishes to thank Nisha Yadav for her contribution in evolving the manuscript. The author also wishes to record his deep appreciation for the unknown referee and the editorial board of *Current Science* for their hard work in significantly improving the manuscript.

Received 1 June 2015; revised accepted 22 August 2016

doi: 10.18520/cs/v111/i9/1456-1464