I. BIG HISTORY'S PHASES AND LONG-TERM TRENDS

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Expansion and Integration Phases in the Major Stages of Big History

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Abstract

The three major stages in extended evolution towards increasing complexity: life, humans, and civilization, can be viewed as separate logistic developments (or learning curves). Each stage has an initial rapid expansion into a new niche followed by a slower integration and synthesis in preparing for the next growth stage. These expansion and integration stages are summarized as: 1) life extending around the Earth then integrating towards primates; 2) the expansion of the primate branch from forests leading to adaptive humans with an integration of tools and language in agricultural villages; and 3) expansion of civilizations towards an integrated technological-based system. This is also seen in the earlier physical development of the Universe from the expansion after the Big Bang towards planet formation through gravitational collapse. There are also indications of substructure and geometric temporal patterns in each major stage. The duration of each subsequent stage is reduced by about a factor of 1,000 (i.e., life beginning about 5 billion years ago, human evolution about 5 million years ago, and civilization about 5 thousand years ago). Each stage seems to be formed by about 6 nested sequential transitions (steps) with the duration of each subsequent transition being reduced by about a factor of 3 (note the 6 factors of 3 between steps give the factor of 1,000 between stages). Some possible explanations for these factors are reviewed.

Keywords: *energy, environment, information, logistic.*

Introduction

In the development of the Universe, there have been many studies identifying the seeming increasing rate of development on Earth of life, humans, and civilizations (*e.g.*, Modis 2002). Each of these three major phases has a unique way to store and transmit information (through DNA, the human mind and language, writing and artifacts). The capacity and speed of each information mechanism has been increasing with subsequent phases, transitioning when the previous seems to reach its capacity (Sagan 1977). The process of evolution seems to include the development of new organization and information to exploit the capture of more energy flow (*e.g.*, through photosynthesis). As the system maintains and grows with the new energy source towards a higher and more complex level from thermal equilibrium, environmental constraints arise. A new way to address the environmental constraints requires information and development of new techniques and organization to continue growing, thereby leading to the next phases of growth (LePoire 2015a, 2015b).

This type of growth (also known as logistic, 'S', or learning growth) is observed in both ecological systems and markets, when a species or product enters, grows and diffuses through a new environmental niche (Marchetti 1980). The early growth is close to exponential but eventually, however, further growth is increasingly hindered by the environmental system limitations. The growth slowly continues towards a stable size, the carrying capacity of the environment. This pattern of initial rapid expansion, inflection at the midpoint and later slowing is also called an 'S' curve due to its shape. Besides this simple pattern of transitionnal growth, there are systems which demonstrate an overall 'S' curve but each point along the curve represents an 'S' curve of a subset of the system growth. For example, a field might be very complicated and so it might be learned with topics which are a subset of the field. Each topic has its own learning curve. The sequence and rate of learning new topics form the overall 'S' curve. This more complex set of learning curves is referred to a nested learning pattern.

For example, the rate of physics discoveries seems to demonstrate this nested logistic growth (LePoire 2005). The first modern physics discoveries started with classic mechanics of particles, waves (optics), and gravity with the likes of Galileo and Newton. These topics were extended to other forces such as electromagnetism and to statistical systems in thermal equilibrium in the mid-1800s. Some thought that near the end of the 19th century those physics discoveries were almost done. But limits were reached both in speed and size leading to the revolutions in relativity and quantum physics where the particles and wave aspects behaved with statistical uncertainties instead of the previous deterministic assumption. The nuclear force was also discovered during this period often referred to the golden age of physics in the 1920s–1930s. Then the pace of physics discoveries slowed as the theories needed integration under a common consistent framework. This began with quantum versions of the forces and particles, and continues to this day to understand the integration of quantum physics and general relativity of gravitation. These steps in discoveries of physics seemed to occur as a set of logistic transitions forming an overall logistic growth pattern.

One interpretation of Big History (Spier 2010; Snooks 2005) is that the three major stages discussed before life, humans, and civilization, form the first half of an accelerated learning (or logistic or 'S') growth pattern (LePoire

2016). These three major stages started at about 5 billion, 5 million, and 5 thousand years ago. (While more precise times are known for the beginning of the Universe at 13.8 billion years ago, and the formation of the Earth at 4.54 billion years ago, this paper works with geometric factors, so an approximation on a logarithmic scale is used. The approximations are within 10 % of the more precise values. Also, the beginning of each of the stages is uncertain and often not well defined so the times chosen are close to the Earth formation, the splitting of the evolutionary branch that would lead to humans from the other apes, and the formation of multi-city states with hierarchy.)

Each stage developed over 6 (nested) steps with each subsequent step being about a third the duration of the previous. These 6 steps then make the stage's geometric acceleration factor the sixth power of 3, which is about 1,000, as seen in the pattern of stages above (actually, the step factor would be the square root of 10 which is about 3.14, but it is rounded to 3 for convenience). Furthermore, the duration of the Universe from the Big Bang to the present is approximately one step factor (3) larger than the history of the Earth, although this step is quite different in that the evolution takes place through cooling and gravitational attraction rather than through natural selection evolution.

To gain a perspective on these factors, if the time values of the 3 major stages are plotted on a line (*i.e.*, 5 billion, 5 million, 5 thousand) with the line being 1 kilometer long which represents the age of Earth, then the development of humans would start at 1 meter from the end. All of written civilization history would occur in the last 1 millimeter. If the time between the Big Bang and Earth formation were added, the line would be about 3 kilometers. A human generation scale of 50 years would be 10 micrometers, less than the width of a hair.

The remaining parts of this paper investigate the pattern of events (Christian *et al.* 2014) in 6 steps of each of these stages. The pattern is related to a logistic (learning or 'S') transition in that the first set of steps are the expanding phase and the remaining set of steps focuses on the transition for the next stage. Keep in mind: 1) these factors are just estimates although others have identified the factor of 3 before; 2) the identified beginning times for each of the steps is only a rough approximation; and 3) the transitions between the information system for each stage (DNA, language/mind, writing) occurred with long development times, *i.e.*, developments of animal nervous systems and brains were prerequisites for human brain development. The emphasis is not the well-known events but instead the relative timing of events and the stage's pattern of niche expansion and focusing.

The Development of the Universe

The Universe also seems to have developed with an expansion followed by a focusing phase. The universe started with a very hot 'Big Bang' and cooled through expansion. Events happened at first rather rapidly as forces, particles, nuclear reactions occurred within the first three minutes (Weinberg 1993). Later atoms formed allowing the thermal light energy to continue as we now see in the cosmic microwave background radiation. Then the universal attraction force of gravity started pulling matter together to form galaxies, stars, and planets. This focused on matter and energy to facilitate the next phase of evolution – life. It took quite a while to generate the conditions for rocky planets like the Earth to form. After about an hour after the Big Bang, the only nuclei for elements were hydrogen (mostly protons) and helium (2 protons and 2 neutrons). The elements necessary for the formation for rocky planets and life were made later in stars and then dispersed through supernovae explosions of those stars. The material was recycled this way through a few generations of stars. This leads to a period of time where stable sun-like stars and rocky planet formation were most favorable (RAS 2011), *i.e.*, after a few generations of stars (*e.g.*, after 3 billion years after the Big Bang) but before the hydrogen to fuel the stars significantly diminishes (about 7 billion years later).

For the case of Earth, it formed about 4.5 billion years ago. The Big Bang is estimated to have occurred 13.8 billion years ago. The ratio of these times, 3.07, is very similar to the factor of 3 in the subsequent steps of evolution on Earth.

Life

The way life originated is still not fully understood although many different hypotheses are still consistent with the data. However, once life got started, relatively early in Earth history (fossil evidence identified as being 3.5 billion years old), it took a long time to reach critical steps towards multicellular animals. Instead, the first life consisted of rather primitive and small prokaryotic cells that did not have a separate nucleus and were much smaller than animal cells. These prokaryotic cells dominated for billion of years as the oxygen they generated through photosynthesis first precipitated the oceanic dissolved iron and then began accumulating in the atmosphere. Perhaps, by symbiosis more complex cells developed at 1.6 billion years before the present (when Earth was about 3 billion years old). These eukaryotic cells have greater size, organization and functions. Again it took another long period (1 billion years) for the eukaryotic cells to develop a mechanism to organize a way to form an organism with multiple cells. However, once this was developed, the number of multicellular organism types exploded in the Cambrian explosion (about 500 million years ago). Many of the body forms are not seen today.

After this major expansion of life in the ocean, life-forms began to discover some specialty niches. One of these was the ability to survive on land (about 160 million years ago). Then, by developing metabolism that would maintain the body temperature despite changes in the outside environment (warm-blooded animals), night and colder environment niches were identified and filled about 50 million years ago, by the end of the dinosaurs. Finally, in the food-rich rainforests fruits evolved that depended on mammals to distribute its seeds. This led to the development of primates in the forest canopy which required better vision for navigating the branches (about 16 million years ago).

In summary, the development of life on Earth to primates followed 6 steps with successively decreasing duration, *i.e.*, 5000, 1600, 500, 160, 50 and 15 million years ago.

This initial expansion of life to the Cambrian explosion of body forms was followed by the focusing on special niches of land, night, and forest canopies. This led to the next stage of evolution – that of the humans and their specialized brains. At this time the capability of DNA to further enhance the information processing became marginal and a new mechanism for information storage and transmittal the human brain started further development.

Human Mind

The branching in the primate evolutionary tree leading to humans and the other to chimpanzees occurred about 5 million years ago. Weather conditions in Africa's Great Rift Valley led to the expansion of grasslands into the previously forested areas. Hominids adapted to this situation by developing a more general way of living including a more varied diet (*e.g.*, scavenging) and the ability to walk on two legs (about 1.6 million years ago with *Homo Erectus*) which helped in seeing further, carrying food, and running. The lack of any well-honed predator characteristic (such as claws or sharp teeth) or defensive strategy (such as speed or protection) led groups to form with rudimentary communication to coordinate food gathering and defense. About 0.5 million years ago the control of fire helped in the digestion process by cooking foods so that energy could be allocated from digestion to increasing brain size. The generalization of human capability to adapt to environments enabled great migrations across much of the Eurasian continent.

A positive feedback then continued among larger brain size, social organization, and better control of the environment (through technology). The human brain size mostly increased after about 160 thousand years ago when modern humans, *H. sapiens*, first developed with an expanding toolkit of abstract language and later more refined tools at 50,000 years ago. Pressures on resources in certain locations led to a more intensive use of the land that led to the agricultural revolution at about 16,000 years ago. These sedentary cultures led to the formation of villages and the need to store and protect the agricultural harvests, preparing the environmental conditions for the development of larger communities in civilization.

To summarize, in this stage the branch of primates leading to humans expanded the ability to adapt in various environments with bipedalism, basic communication, control of fire, and an adaptable mind. This led to a positive feedback cycle focusing on refined symbolic language, external stone, bone, and antler tools, social organization, and the great leap towards better control of the environment – agriculture.

Civilization

Agriculture started in many places around the world with different domesticated plants and animals. Agriculture allowed humans to better control their environment and food source although many social and environmental problems arose such as the need for hierarchical systems to gather, store and redistributed excess agricultural production while still defending against others that saw the storage as an easy target. Environmental conditions (Ponting 2007) were also more intensive as sanitation needed to be accomplished within the community instead of moving onto a different location. Early civilizations started at about 5,000 years ago (slightly different times in Mesopotamia, Egypt, and China). About halfway through this ancient civilization step, less stable civilizations occurred during the Greek Dark Ages in part due to innovations in using iron. After adaptation to these weapons, again larger and longer lasting civilizations occurred with the last of the ancient civilizations (Romans and the Chinese Han Dynasties). However, these civilizations depended significantly on forced labor of captured peoples or slaves which diminished the incentive to develop energy technologies from sources such as wind and water. After the Roman and Han collapse (which lasted until about 400 CE, *i.e.*, 1,600 years ago), the slow development of wider trade and newer forms of finance finally led to a more sustainable growing economy with the Commercial Revolution (Lopez 1976).

While many civilizations formed extended trading networks (the peak of the expansion phase), the Chinese dominated economic development in this period. Despite the fact that many scientific and technological discoveries were made in China, it was in Europe where these inventions eventually formed a critical mass to focus a sustained interest and motivation to apply to science, technology and new governmental forms starting in the 'Modern Age' of about 1,500 (500 years ago). Many explanations have been hypothesized about why this occurred in Europe and not elsewhere (Goldstone 2008). The need for different energy sources due to the dwindling forests in England, led to the virtuous cycle of technology development of coal, steel, and railroads initiating the first industrial revolution (about 1,800 or 200 years ago). The necessity of the further development of fossil fuels such as oil led to many international conflicts such as the need for Japan and Germany to maintain oil supplies during the Second World War. The competition in these conflicts led to the need to develop information further at a faster rate leading to the first electronic computers in the early part of the information age (about 1,950 or 50 years ago).

To summarize, the development of fixed agriculture villages (15,000 years ago) led to the need for greater hierarchy in administering excess food and goods while also protecting the inhabitants (5,000 years ago). This required writing and technology innovation applied to the hierarchical social organizations. The more complex states expanded control over larger areas and increased innovation diffusion with trade (growing after 1,600 years ago). A path to greater prosperity was identified with focus on scientific knowledge (500 years ago) and applied technology using fossil fuels (200 years ago). This limited resource led to conflicts which required greater electronic information technology (50 years ago).

Dynamics of Environment, Energy, Information, and Organization

What are the dynamics within these steps? The dynamics of a system exploring a new environmental niche is at first rather rapid growth while utilizing newly identified resources and enabled by the new application of information in an innovative coordination system (*i.e.*, organization). The system is maintained at a higher level of energy flow which solves the problem of the system to naturally descend. As the system grows, new environmental impacts due to the increased energy flow are no longer easily handled. This quantitative shift results in a limited capacity to grow the system as any attempts to easily modify one part of the system leads to nonlinear side effects in other aspects. As the growth of the system is slowed, new technology (energy and information) and organization patterns are sought to solve the problems. A variety of solutions are proposed and tested. Ultimately one system is identified that has the best prospect for growth (natural selection). This continues the development process into the next phase.

For example, in the transition from hunting and gathering to agriculture, hunting required more land but as the population slowly grew, alternatives to hunting were explored especially in stressful locations. Through many years the groups identified plants and animals for domestication, and selection which allowed a higher energy flow (farmed food) and population density. Since the new agricultural lifestyle produces more food for higher growth, the pressure on the hunter-gatherer lands increased, leading more people to switch to agriculture. However, as agriculture villages grew, there arose a number of new problems such as disposal of the waste, storage and protection of the excess, recording property and contracts, and maintaining sustainable soil. Eventually, as more villages are founded, conflicts over land and access to water and resources increase. The village organization reached the limit of resources and environment. This led to the next step of energy, organization, information, and environment as some villages group and reorganize with a hierarchy to support new functions such as rules, defence, and common understanding (religions) which starts the next subphase of civilization with some of the labor now supplied by forced labor of the captured villages who had not formed a higher level of organization.

The hypothesis that complex systems evolve by capturing more energy flow, growing, and periodically reorganizing to mitigate the effects of environmental degradation is consistent with thermodynamics (Schneider and Kay 1994) where there is an external energy source (the Sun). This growth requires greater capture of the energy flowing from the Sun before it is reradiated out into space at a lower temperature. This greater energy flow is extended by using information in the environment to periodically reorganize to a higher complexity. This non-equilibrium organization, however, contains the seeds of its own destruction since eventually greater energy flow leads to nonlinear problems caused by limited resources and environmental issues. This is resolved by continuing the process of growing, capturing more energy flow, and reorganizing.

The growth of global population seems to indicate a mechanism faster than normal exponential growth (Kremer 1993). The trend seems to indicate that the fractional growth rate was proportional to the current population (instead of being constant as in an exponential growth). This has been explained as an indication that increasing use of energy and technology leads to an increasing growth constant. This type of growth is characterized by a population that grows as $1/(t-t0)$ where $t0$ is some time at which the population experiences a 'singularity', *i.e.*, tends to infinity. In reality, the population size will be constrained by environmental levels before this and in fact, the rate of population growth has recently started to decline (while the population continues to grow). This pattern can also be expressed that the product of the population and the time to $t0$ is a constant. For example, the population at the end of a step is about 3 times than that of the population at the beginning, since the time to the present (near $t0$) has been reduced by a factor of 3.

The growth of energy flow (Niele 2005) in the evolving system should increase faster than the population since it is expected that the energy intensity (energy flow per unit) increases. For example, warm-blooded animals need more energy flow to regulate temperature at night. In human development, the use of fire allowed the energy of modern humans to be directed more towards the brain than the digestive system since the cooking did a large part of the energy intensive digestion process. While others have focused on the energy flow per mass of material and successfully applied it to the complexity classification of natural and engineered systems (Chaisson 2004), here we focus on the amount of energy (free energy, exergy, or useful energy) that flows through the evolving system. At first the system was relatively small. For example, a hydrothermal vent is one location identified as a possible place for life to first develop. One typical vent has a chemical potential energy flow of a few kilowatts of which only a small fraction is used by lifeforms. The amount of power used in the world today (2×10^{13} watts) is about 10 billion times larger than a typical hydrothermal vent. Another insight might be gained by comparing the base human metabolism (roughly 100 watts) to the average energy intensity (energy per person) today in the U.S. (10 kilowatts) which is 100 times larger. With this factor, the energy per person would have to expand by about 1.5 times faster than the population over the 11 steps during the evolution of humans and civilization. Since the population growth factor is about 3 per step, the overall energy flow from increasing population and energy per person would be about 4.5. This gives a possible indication that the system is a complex adaptive system (CAS) (Jantsch 1980) since the universal constant for their ratio of driving parameter is the Feigenbaum number of about 4.67. This could indicate that the system is behaving like an evolving CAS, where the steps occur when the overall energy flow in the system increases by about 4.5, but then accounting for the increase in energy intensity, the population grows by a smaller factor of 3 for each step.

Discussion: Further Questions

This raises many questions. Why is the major geometric temporal scaling factor for the phases 1,000? Why is the geometric temporal scaling factor between subphases 3? What happens if there are enough resources or information necessary for a transition to the next subphase? What happens next as the duration in the sequence becomes too small for any significant amount of change?

So what is the origin of the factor of 1,000? The answer should lie within the capacity of the information system to support the necessary organizational changes. This can be seen in the three previous information systems of DNA, brain, and writings/culture. The genetics of animals evolved to fit their environment. It was not an active part of the animal (Lamarckian evolution although some aspects might be valid). Instead, it seems like random mutations are formed and tested with natural selection. This is good to develop advantages in speed, armor, teeth, and claws but not too helpful in developing collaborative strategies which require collective memory, communication, and predictive planning. A more volatile but responsive information system developed with the brain, especially in humans, which required a long period of time for guided development of newborns. Also, employing a generalist approach to food gathering led to an approach to collaborate by using the available resources in the environment including tools such as plants, stones, bones, and clay. Later writing and technological development occurred when agricultural villages required greater collective learning over a wider area.

An early estimate (Sagan 1977) was that the information available from DNA peaked and was supplemented by the higher capacity brain system in animals leading to human development. This peaked later leading to further supplementation by writing. The limits of the information capacity seemed to be a factor of 1,000 between the DNA and brain systems.

A few recent approaches to applying thermodynamics to evolving systems might supply insights to these factors. Bejan and Zane (2011), Bejan and Lorente (2012) developed the constructal law and constructal theories to explain how systems out of equilibrium, *i.e.*, energy flowing through the systems, evolve to best intercept the useful energy before the energy is completely converted into heat. This was applied to animal dynamics, sports, economics, river flow, and conventional engineered systems. As their energy flow increased, the systems periodically change in organization with increased ability to deal with the entropy caused by the increased energy flow.

Another approach to explain the factor of three is given by Jose Faixat (2011) who considers that the first step sets the timescale. The logistic development of this phase consists of the initially rapid growth followed by a similar duration phase of slower growth limited by the capacity of the system. He then considers what would happen if this cycle period were continued in a fractal manner, *i.e.,* a second harmonic of the initial phase. This leads to the factor of 3 found here and by others (*e.g.*, Panov 2011; Snooks 1998).

The factor of 3 in each step along with the number of nested steps (6) found in the history of physics development would be consistent with the stage time factor of 1,000.

Other questions deal with the situation where the transitions might not have been possible given the resources in the environment. For many of the transitions, there were many independent trials being tested. Again in evolution, the trial that succeeds is the one that can propagate the best. This could be seen in the transitions to civilization – many early success have been documented although many in the New World such as the Mayans and the Mississippian civilizations seemed to collapse after a long successful development (Tainter 1996). This could be a bit disconcerting in that the major transition now, there seems to be only one system left, the global system. If there is only one attempt at this transition, then missing it through lack of learning or resources might cause the process to stop. For example, much of the progress of the past century has been supported by the use of easily extracted fossil fuels. If the transition to a new sustainable society is not achieved before either the fossil fuel resources are too diminished or their use has caused irreparable harm to the environment, a second chance might not be an option. The nonlinear aspects of the global system are seen in the global intertwined issues of environment, energy, population demographics, potential epidemics, technology development and terror risk (LePoire 2004, 2010). It seems each issue cannot be independently solved but must include some systemic reorganization of global cooperation.

But what if the transition to a more sustainable energy system is found that also alleviates other global issues? One extension of the pattern towards increasing rate of change leads to chaos since the new technologies and organizations are not tested on the time scale where the many possible scenarios might arise. This can be seen in the rapid development of IT technology which allowed greater communication and trade. But at present the unintended negative aspects are being realized in loss of privacy, ability to intentionally miscommunicate, cause havoc with hacking systems, implicit obsolescence of products and training, and increasing the cost of participating in the system (cellular and IT services costs).

A different extension of the pattern is that the rate of change starts to reverse itself as a logistic growth pattern does by the middle of the phase, *i.e.*, instead of an accelerating rate of change, the rate of change might stall (although the change continues at first at a rapid pace), and then might slow (Linstone 1996; LePoire 2013). Besides the logistic pattern, there are natural systems with limited capacities that tend to follow a pattern of increasing complexity but then reverse the complexity before going into chaos (Stone 1993). This would mean a period of simplification. Just slowing down the rate of change would be a simplification since products and training would last longer. For example, the increasing introduction of IT systems now barely gives the users enough time to learn the new features and idiosyncrasies of new systems before they are replaced with another to be learned.

Summary

The development of technological civilization on Earth occurred through three major evolutionary stages: life, human, and civilization. Each stage introduced a new information system (DNA, brain, and writing/technology respectively) that increased the speed in which change could occur. This is seen in the durations of the stages (5 billion, 5 million 5 thousand years), *i.e.*, a speedup factor of 1,000 from one stage to the next.

Each of these three stages consisted of 6 sequential steps that had durations that shortened by about a factor of three. This is consistent with the stage duration reduction factor of 1,000 since duration reduced by 6 factors of 3 leads to an overall reduction by a factor of 1,000. In each step changes occurred in the energy flow, environmental impact, organization, and information. The first part of each stage showed expansion into new environments. Then, in the second part of each stage, expansion slowed and led instead to a focus of the evolutionary pathway for the next phase.

Some potential causes of the geometric temporal scaling factors of 3 and 1,000 were discussed. Some current research from highly non-equilibrium thermodynamics might give insight into their values. A combination of hyperbolic population growth and increasing energy intensity might lead to a total energy increase by a factor similar to the Feigenbaum number for the development of complex adaptive systems.

Further questions and issues were discussed including the extension of the pattern into the further past (cosmic history) and future. This expansion and focusing aspect of each stage was extended to include the non-natural selection evolution of the cosmic phase growth from the Big Bang to the development of planets. The current pattern of steps of increasingly shortened durations does not seem to be sustainable. Instead, a large scale logistic pattern might develop in which future phases might form the second half of the large logistic growth curve by the rate of change to start to decelerate. This might be due to the need to form a sustainable energy flow independent of fossil fuels and the need to collaborate on an international scale to address many issues. There is also a question what happens if the environment and resources are not adequate to continue the pattern. If the current transition is not realized in time, a second attempt fueled by the use of inexpensive fossil fuels may not be possible.

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Appendix

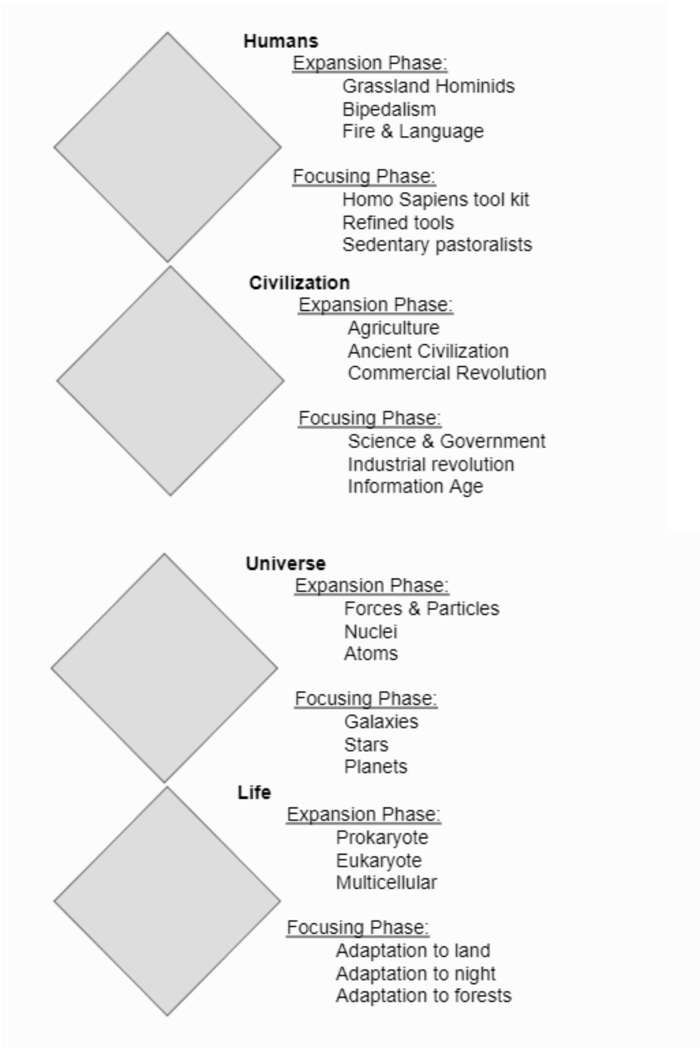

Fig. 1. Expansion and focusing steps in each of the major stages

Table 1. In the evolution of Life stage, simple characterization of environment, energy, organization, and information changes in each step

Step	Environment	Energy	Organization	Information
Prokaryote	First life. Maybe hydrothermal vents or ponds	Anaerobic energy from environment, *e.g.*, chemical or photosynthesis	Containment and control of cell	Ability to sense and adapt to the environment
Eukaryote	Available oxygen	Aerobic energy through mitochondria	Separate nucleus with symbiotic relationship of organelles	Communication among cellular organelles
Multicellular Organisms	Ability to remove waste and deliver oxygen to internal cells	High enough oxygen level	Growth from single cell to organized multicellular organism	Communication between cells and development from single cell
Development of Terrestrial Animals	Ability to adapt from water environment	Plants and higher trophic levels	Development of land-based niches	Increasing care of eggs
Mammalian Development	Need for more energy to support elevated temperature at night	Warm-blooded metabolism	Mammalian development with care for young	Possible learning across generations
Prosimian Development	High diversity jungle with capability of canopy environment, threat of climate change	Evolving fruits	Social groups	Basic communication in groups

Table 2. In the evolution of Humans stage, simple characterization of environment, energy, organization, and information changes in each step

Subphase	Environment	Energy	Organization	Information
Transition to Grasslands	Drying environmental conditions	Incorporating food from grasslands	Learning new grassland environment	Communicating additional dangers
Bipedalism	Grassland support large mammals	Scavenging	Organized hunting and scavenging	Hunting communication
Fire and Language	Dry conditions and need to control fire	Fire for protection, heat, and cooking	Culture around sharing fire and food	Language

Subphase	Environment	Energy	Organization	Information
Homo Sapiens Tool Kit	Competition with other hominids	More energy to brain	Culture and tool speciali-zation	Abstract thought
Refined Tools	Exploring new environments	Adaptation to environmental resources	Innovation and diffusion with other groups	Passing tool skills across generations
Sedentary Pastoralists	Ice ages	Starting domesti-cation of plants and animals	Towards village	Learning plants and animals

Table 3. In the evolution of Civilization stage, simple characterization of environment, energy, organization, and information changes in each step

Subphase	Environment	Energy	Organization	Information
Agriculture	Sanitation in settled village	Additional work hours	Storage, village hierarchy	Contributions and property
Ancient Civilization	Soil depletion	Forced labor	Money, concen-tration in cities	Writing, laws, contracts
Commercial Revolution	Disease through trade	Water and wind	Banks, trading networks around financial centers	Books, financial records
Age of Discovery	Transfer of diseases across Atlantic	Wind	Capital for-mation, nations	Printing
Industrial Revolution	Water (germs), air (coal)	Coal	Factories, democracy	Public schools
Information Age	Climate Change (Carbon dioxide from fossil fuels)	Oil	Networks, inter-national agree-ments	Computer and Internet