International Big History Association

IBHA Members Newsletter

Lawrence Husick is an IBHA member and a Senior Fellow at the Foreign Policy Research Institute, where he co-directs its Wachman Center program on Teaching the History of Innovation. In a recent lecture he gave, called, "From Stone to Silicon: A Brief Survey of Innovation," he said that "Innovation" is not just inventions; it is a process of making changes by introducing valuable new methods, ideas, or products. "Innovations" are the things themselves—the ideas, methods, and processes. It's not simply that better mousetrap; it's different ways of thinking and doing. Innovations may of course be inventions, but they may also be beliefs, organizational methods, and discoveries. An innovation is a value-creation mechanism. It is the way we humans manage to extract more value, generate more economic surplus and therefore more leisure time. (http://www.fpri.org/)

We can approach this topic through a "tough question." Not "what is the most important innovation in the history of man"—that one's easy. People can and do differ, but most come up with just one. No, the tough question is, "What are the 25 most important innovations, in rank order?" Rank order here means the absolute value of the impact of an innovation, be it for good or ill, on human life, times the total number of lives affected. There is no requirement that the lives impacted have any idea about the innovation or how it works. Most of us have no idea how those little people get inside our television sets to entertain and inform us, and yet we watch television. Innovations are made and affect us, and we in turn affect the course of innovation, even without deep understandings of the mechanisms.

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IBHA members are engaged in a variety of important projects that are part of Big History. Please let us know what you are doing that is related to Big History .

The IBHA is now incorporated; information about regular membership rates are available on our website at http://ibhanet.org/. Information about Big History, links to other BH sites and materials, and more is also on our IBHA website.

David Christian, President of the IBHA, was introduced by Bill Gates at the 2011 TED conference, where he gave a presentation on Collective Learning and Big History. The video of this lecture is linked from http://ibhanet.org/ David's book, *Maps of Time*, will soon be available in a second edition.

Please plan to participate in the IBHA conference, August 3 - 5, 2012 at Grand Valley State University in Grand Rapids, Michigan. More information is at http://ibhanet.org/

In my list below, there may appear to be a bias toward newer innovations. That's simply a result of the ranking formula. Looking at world population in the common era, since the year one (because in the year zero, no one had yet invented the concept of zero—that came around 600 or so), most of the people who have ever lived have lived in the last 200 years. Thus, even small innovations have tremendous impact when multiplied by the population experiencing them.

The ranking is constructed from the considered opinion of many people, too many to name. It's neither right nor wrong—the purpose of this discourse is to provoke argument. What is included wrongly? What is left off in error? How is the order dreadfully, woefully messed up?

And now, a brief tour through the history of innovation, working backward from #25:
Innovation #25 is **relativity and quantum mechanics**, invented in 1912. We are a scant 103 years since special relativity, since Einstein's miraculous year of 1905, and everything we touch in industrialized society owes a debt to Einstein and his colleagues. Our entire way of looking at matter and the universe changed in the seven years from 1905-12. In fact, you would not be reading this paper on a screen, talking on the telephone, watching television, driving a car, or using any other modern marvel without the solid-state electronics that were made possible by this revolutionary innovation in how we think about the structure of the universe, from the largest galaxies down to the smallest subatomic particles that allow us to make microelectronics and nanotechnology. In fact, one of the more troublesome and problematic challenges of the twenty-first century—how to get rid of the atom bombs we created in the twentieth century—also owes its existence to relativity and quantum mechanics.

$$\mathcal{L} = \frac{mc^2}{\sqrt{1 - \frac{v^2}{c^2}}}$$

Innovation #24 is **electromagnetism**. Again, the idea that we can harness electricity to do work that used to take back-breaking labor by people and animals is a revolution. Hans Christian Orsted first noticed the effect in 1820; in 1821, Michael Faraday came up with an electric motor. Most of the motive force in modern society, and all the electricity that T. Boone Pickens advertises as being created by burning fossil fuels—all the things that let us ride up in elevators and escalators, turn on our cars, have electric motors do work for us, and have electric lights—all of it comes from theories of electromagnetism. How important is electricity? Five years after Edison installed the first electric light bulb in Manhattan, the first generating plant, the Edison Electric Company, wished to celebrate its anniversary by turning off the lights for five minutes at midnight on New Year's Eve. The mayor of New York pronounced that this would be a hazard to public safety and prevented Edison turning off the power. Think about going to the grocery store in the absence of the electricity that runs the freezer and refrigerator cases. Think about our food distribution system, our communication and transportation systems. Nothing we do in an industrialized society is possible without electricity. Indeed, a critical measure of our success in Iraq and Afghanistan is our ability to build infrastructure and keep the lights on in.

Innovation #23 is **evolution and natural selection**. Darwin first posited this theory in On the Origins of Species in 1859. The theory was 25 years in the making, but Darwin, for reasons we now understand, was dreadfully afraid to publish it. It changed the way we view our place in the natural order. Some would say it forever debased humankind,

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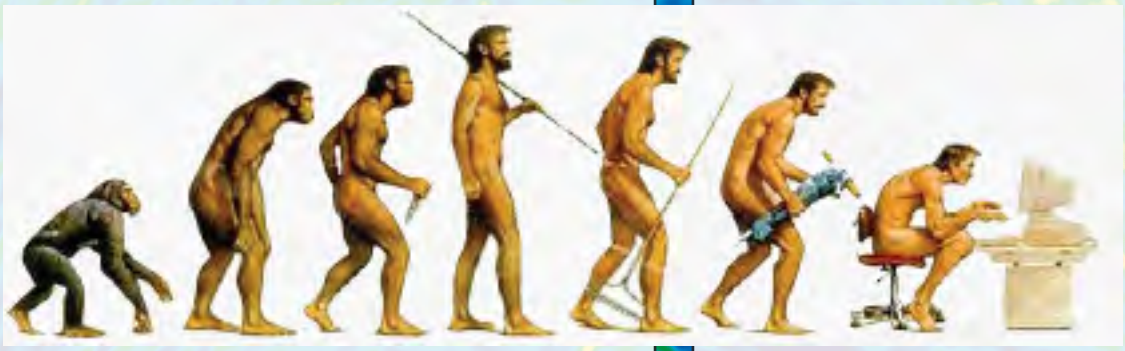


because Darwin made it clear that we are just animals—animals of a special sort, but animals nonetheless. Our understanding of evolution and natural selection has since informed all of our understandings of biology, ecology, healthcare, population dynamics, and the many consequences of human actions in the natural world.

Innovation #22: Before electric power, there was steam power. The first **steam engine** was the French Papin engine of 1690. From 1690 through the early part of the 18th century, through Savory to Newcomb in 1712 and finally to Watt, the steam engine made a huge difference because it multiplied man's ability to do work. Before the steam engine, you needed draft animals to do anything substantial. The mining of coal was incidental and small-scale. The steam engine, which was used to drive the pumps that could drain the mines, made mining coal practical. You could finally go deep enough to get coal, which in turn was a primary fuel for the steam engine. This is an example of an innovation fueling and making available another innovation that in turn fed back on the first innovation. One of the things we learn in studying history is that there is no straight line of ascent—we always zigzag. The steam engine was truly a step forward, although it took over 100 years for it to come to final form and end up driving locomotives and steamboats and changing transportation forever, which also changed economies and nations.

Innovation #21: Before the steam engine, if you wanted to do serious hard work, you did it with **water power**. Water power was first exploited in 240 BCE, in the Fertile Crescent area in the Middle East and in Asia Minor. It is a tremendously efficient innovation, because it drives heavy millstones without draft animals. It changes the motion of falling water into useful work. Water power remained an important part of society and the economy well into the developments that sparked the Industrial Revolution in Europe. In fact, some would argue that the abundant rainfall and number of rivers in Europe created an economy based on water power that permitted Europe to develop technologies that outstripped the rest of the world beginning in the late Renaissance. The same is true of the factory system of New England, where mills were built to harness the rivers of Massachusetts, New Hampshire, Rhode Island, and Connecticut.

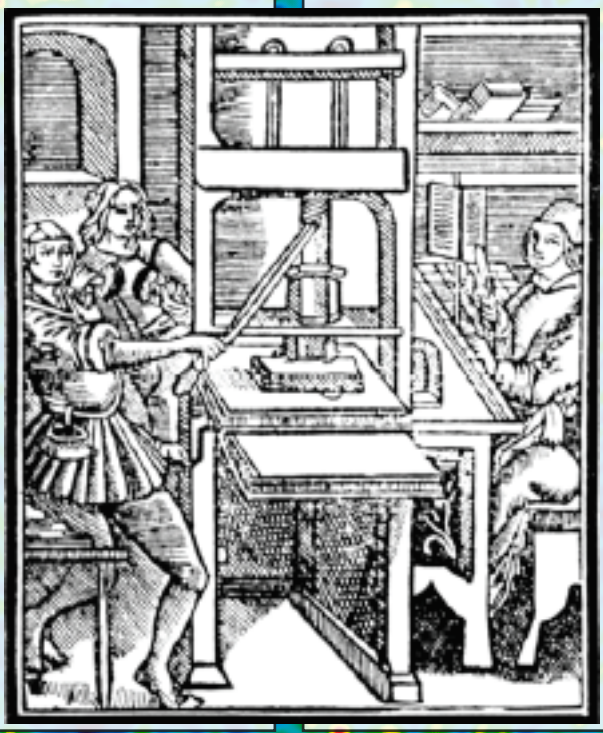
As to efficiency, a car's gasoline engine can reach an efficiency level of only about 30 percent in terms of conversion of fuel to effort. An "undershot" water wheel, where the water flows beneath the wheel, invented more than two millennia ago, is over 25 percent efficient. And if you build a sluice and make the water an overshot water wheel, so the water falls on

top of the wheel, the efficiency rockets to 75 percent. If we could build cars like that, a 100 mpg car would be no problem at all. The problem is just building a big enough water tank.

Innovation #20 is more of a world view. It is the concept of **science** itself, which until well past the time of Thomas Jefferson was called natural philosophy. There was no differentiation between the study of philosophy and the study of man's place in the world and his relation to God. Newton himself said that he was trying to understand the world and the universe so that he could understand God's plan. Einstein echoed this in saying that he studied physics because he tried to understand the "mind of God."

The use of the scientific method and of objective systems of understanding and codifying the world originated in the sixth century BCE in Greece, when we went from observation to theory. Observation had long preceded theory; it was what you did if you wanted to understand the calendar or astronomy, when to plant and when to reap. But that was purely empirical. It was the Greeks who gave us this idea that there was some objective theory that knit things together that was outside of but understandable by man's experience. They also gave us formal systems—mathematics, logic, statistics. Later thinkers gave us concepts like place value (think about trying to write big numbers in Roman numerals) and, as discussed earlier, the very concept of zero.

Innovation #19, which appears at the top of many lists of innovations, is **moveable type**. Most Westerners would credit moveable type to the Gutenberg press of 1436. But in fact moveable type goes back to imperial China in 1040. There the type pieces were ceramic; Koreans took this invention forward about 200 years later using some metals. But the difficulty is that in pictographic languages, such as Chinese and Korean, which have 5,000 characters, the time required to find and remove one piece of type from a box system of 5,000 made it impractical and inefficient to set type. The Koreans and Chinese also had social institutions that limited printing to a bureaucratic and governmental system. There was no private market for printed materials, and eventually those cultures went back to one-off woodblock printing. Fortunately for us, Gutenberg came up with the idea of moveable type, special inks, and an efficient press, and understood the advances in what are called the type metals—tin, lead, and antimony. His innovation found a ready market because by that time, every educated person in Europe wanted the Vulgate Bible. The desire to have a Bible of one's own drove the market.



This is also an example of failures of protection of inventions. Gutenberg made all of his apprentices and everyone who worked in his shop sign a draconian nondisclosure agreement. And yet, within five years of Gutenberg's first use of moveable type, the technology had spread all over as his apprentices left and formed their own shops, and thus has it ever been.

Innovation #18 is **fossil fuels**. Today, when we hear fossil fuels, we tend to think that maybe we've gotten into trouble with this one. But fossil fuels have been critically important in the last hundred years. The first recorded uses of coal were around 1,000 BCE, in the Middle East, when it was said that there were rocks that burned like charcoal. These were exposed coal scenes where people could simply chip away at the surface to collect them, but they also produced very hot, sustainable fires. Coal and charcoal contributed to many other important technologies. Getting beyond coal, however,

had to wait a long time. The first use of natural gas drilled for its own purpose and not, for instance, for a flame (which became known as the Oracle of Delphi) was in 1859, when we drilled our first well in Ohio. In the same year in western Pennsylvania the first oil well was drilled and the first oil refined. In the century and a half since then, we have come to understand that our addiction to fossil fuels is perhaps irreversible.

Fossil fuels changed the way in which economies operated. For the first time, the density of energy and fuel made it possible to make things portable. That meant changes in transportation. At the Ford Museum in Dearborn, MI, there are some steam engines that stand 80′ high. Today we can build engines small enough to power weed-whackers, barely the size of a softball. And it's all because of the energy density of fossil fuels. We will not replace fossil fuels completely in our lifetimes, but we are beginning to understand that petroleum and natural gas may be too valuable to burn to get from point A to point B. That is because these hydrocarbons are also the stuff of which we make miracle drugs and plastics and thousands of other things we consider indispensable.

Innovation #17 is the **specialization of labor**, or some would say tribal and clan organization. The idea that some people do some things better than others has been with us since well before the dawn of recorded history. Perhaps the first instance of that was the recognition that some people are well suited for hunting and others for gathering, that some people are better out there in the field and others make food that's tasty. Sexual dimorphism also gave us the ability to separate roles. We continue to push the boundaries of that today in society. Traditional societies have those roles relatively well set, and one of the great sources of friction in the world is the clash between societies that are overcoming those roles and those that choose not to. But the specialization of labor went far beyond to the specialization of roles in society, so that some people could knap flint and make tools, and others could use those tools. Some could make arrows and bows and spears and others could hunt with them. Some were good at making fire, and others not so good. The idea that you can build a society by specializing those roles freed a lot of people and a lot of time, improved efficiency, and created value.

Innovation #16, paper, ia a relatively recent innovation. Paper was first mentioned by the Chinese in the year 105, and yet the Chinese continued to use other materials because paper was thought of as too fragile, writing too expensive. Paper continued to develop until finally, by the sixteenth century, wood pulp paper became more widely used than rag paper, which created an explosion in publishing and the growth of knowledge. It can really be said that wood pulp paper created the modern educational system. Before that, the cost to create a book and disseminate it created bottlenecks in the economy. With wood pulp paper, publishing began to bloom, and with it, modern scholarship.

Innovation #15 is also at the top of most people's innovation lists: **the wheel**. The first wheel was probably a millstone transported for its own use (as a stonecutter makes millstone in the quarry and then must somehow get it to the mill.) One theory of how the wheel might have developed is the idea of rollers and sledges. These systems were instrumental in

building the Egyptian pyramids and before that the ziggurats of Mesopotamia, and perhaps the megaliths of Stonehenge. The wheel changed how we move things, how far we could go in a day, and how far we could farm from a village. Thus the wheel heralded the domestication of draft animals, because once you decide you're tired of pulling the thing along, you look for something else that's going to pull better.


Code of Hammurabi

Innovation #14 is **formal law codes**. Certainly there were formal law codes before the Code of Hammurabi, who was codifying oral or fragmented law. But by 1,780 BCE, Hammurabi had laid down a formal code of laws, most of which did not deal with criminal law but rather with civil and commercial law. That trend continued through the Egyptian Book of the Dead, even to the Ten Commandments and the Twelve Tables of Rome. The great works of law and literature, including one of the greatest, the Book of Leviticus, show that we have come up with an awful lot of civil law, a lot of ways of saying how people should relate to one another commercially. In effect, we have been simply writing down our politics for thousands of years. But law is a way of reducing the cost of dispute resolution to a society, and thereby increasing the efficiency of its economy. It's much better if you know what you're supposed to do and what happens if you don't. That predictability increases efficiency.

Closely allied with law is **Innovation #13**, the concept of **money**. Money also has a long and storied history. Humankind started out with barter. What do you have that I need? It went with specialization of labor. If someone makes arrowheads all day, how are you going to get the arrowhead from him? You're probably going to trade something you've just hunted with an arrowhead he made. Money comes into the picture as a way of solidifying the power of the state. That's why the Sumerians, the first agricultural urban society, were the first to adopt a concept of money. In other words, I've got a lot of stuff stored, I'll give you something that says you now own it. In effect, it's a form of deed.

We come forward from coins to paper money and finally the thing that enables all modern economies, the concept of fiat and credit currency, which was developed in late medieval Europe, in which letters of credit and letters of mark allowed us for the first time to bank on the power of the state itself rather than on the value of the coinage.

Innovation #12 is **gods and religions** as social institutions. Religion creates social cohesion by creating in and out groups. It gives a priestly class super-authority (authority that doesn't come from who you are, but rather who you represent) and shapes behavior in both prescriptive and motivational ways, all in a tremendously economically efficient mode. If you are a priest-king living in a palace in ancient Sumer, you have a prescriptive authority of saying, "This is the God speaking and not the man," and you have the ability to promise rewards in the afterlife at no particular cost to yourself or the ruling class. It's a debt you'll never have to pay off. Economically and organizationally, religious organization has to be ranked right up there at the top with almost any other economic advance.

Dostoevsky probably put it best in The Brothers Karamazov, when Fyodor Pavlovich said, "Damn it all, what wouldn't I do to the man who first invented God!" To which Ivan Fyodorovich replies that there would have been no civilization if they hadn't invented God, and no brandy,

Shāng Dynasty Oracle Bone Script on Ox Scapula, Linden-Museum, Stuttgart, Germany.

Sumerian inscription in monumental archaic style, ca. 2600 BC

either.

Innovation #11, systems of writing, went from pictographs, whether cuneiform or Chinese in their evolution, with thousands of individual symbols to be learned, to an alphabetic system which evolved from the Phoenicians, through a long period of evolution that we can trace all the way down to our use of Roman script today. The idea that characters can be combined in grammars to represent ideas made possible written records of tremendous complexity and efficiency, calculations as place value was developed, and Gutenberg's printing press. Our alphabet derives directly from something 2,900 years old. One of the only advances thereafter was the development of a separate numbering system, what we call the Arabic numbering system.

Innovation #10, food preservation, arguably first developed around 10,000 BCE in the Neolithic revolution, meant that you didn't have to eat what you killed right away, but could save it for lean times. Portable food sources that are dried, freeze-dried, salted, spiced, pickled, cooked, smoked, or fermented allows travel over longer distances and more efficient migration with animals, changes society, and generates tremendous value. We understand all of these methods and techniques, but many of them have been supplanted by electric refrigeration. It would now be very hard to find salted cod, which was a staple of the northern European diet for 2,000 years. Instead we buy fresh cod or go to Costco, where they routinely fly in a 600-pound tuna caught two days ago in the Solomon Islands in the middle of the Pacific. (I shudder at the carbon footprint.)

Innovation #9 is **metallurgy.** Ancient people built fires that burned hot. They looked in the bottom of the fire pit after a while and noticed there were some things there that were harder than the kinds of stones they were used to dealing with. What were they? What could be done with them? The progression was from copper, silver, and gold to soft metals first mined and smelted in about 4,400 BCE; to the idea of alloying certain metals, for instance copper with tin, to get bronze, which is a harder and more durable metal; to the Iron Age to finally steel. In fact, Damascus steel is probably the first instance of the use of nanotechnology, as carbon nanotubes from the furnaces were

incorporated that made the steel remarkably hard yet not brittle. Metalworking became both a science and an art. In Jared Diamond's theory of Guns, Germs, and Steel: The Fates of Human Societies (1997), steel is the third leg of the dominance tripod of the West.

Innovation #8: Ceramics and pottery. Some of the other things the ancients found in the bottom of a fire pit were pieces of clay that through repeated firings had gotten hard and had their porosity reduced. So you have the ability to make clay vessels, first to store dry things like grains, then fired clay in which you can store liquids, and finally earthenware, stoneware, and porcelain, which eventually in the hands of Chinese became high art. From a simple clay pot unearthed in Syria, 6,600 BCE we come all the way forward to our finest toilets today, which are vitreous china, made by the same processes of molding and firing clay. Our microelectronics also owe a debt to pottery and ceramics. Computer chips are built on a ceramic substrate that conducts the heat away from them. No ceramics, and the chips would burn themselves up and your cell phone would quit working.

Innovation #7, farming, is really a chain of innovation over a long period of time. The first animal to be domesticated is generally thought to be the dog, around 15,000 BCE. (The horse was domesticated on the steppes of Central Asia in about 5,000 BCE, but the horse collar, which would make the horse so useful in farming, would have to wait another 4,000 years.) The domestication of plants began with the bottle gourd, something you could dry out and carry as a canteen. Imagine what it would be like if you couldn't carry water with you when you go hunting. You would have to stay pretty close to sources of water. With a bottle gourd, you could go farther and have greater access to more crops and herds. Wheat was arguably the most important crop in the world until rice—the most efficient crop for converting the nutrients in sunlight into edible material—came along about 5,000 years later.

From the domestication of animals and plants to hydraulic agriculture—the idea of artificial irrigation of crops that was developed in the Fertile Crescent—to the plow and the concept of crop rotation, chemical fertilizers (which didn't occur to us until the seventeenth century), artificial nitrate fertilizers (which didn't occur until we could synthesize them at the beginning of the twentieth century), and finally the Green Revolution in the early 1960s, farming has given us the ability to create unprecedented economic surplus, which many would say gave us the rest of the innovations listed here.

Innovation #6: Clothing. Without clothing, people have to stay where it's warm and dry. It took a long time to go from draping ourselves in tanned animal skins to figuring out how to use a needle to sew them into some sort of a shape, and a longer time still to the weaving of cloth and the making of tailored, layered clothes. In the stone age, not only did you eat what you killed, you also wore it. We've been able to reconstruct the clothes of Utze, a Copper Age hunter, found when a glacier in the Austrian Alps receded. He wore snow shoes lined with grass for insulation. He had a cape made out of woven grass, carried sophisticated animal skin bags for his gear, and he was truly a happy wanderer until someone shot him with an arrow and he died and got frozen in that glacier.

Innovation #5: Symbolic communication. Starting with cave painting, human beings began

Lascaux, France, about 15,000 years ago

to communicate with each other across time and space, not simply face to face. The idea that one could communicate with people through symbols made externalization of information and language possible. It gave us a storehouse of information that didn't need to be transmitted just by showing someone how it worked, whether you were drawing on the walls in a cave in Lascaux or coming up with counters in Aswan that indicate that some dates were brought by camel from a far-away place. At the same time, symbolic communication in Sumer developed into cuneiform, pressing reeds into soft clay and baking them. (We know a tremendous amount about cuneiform because it's really hard to get rid of clay tablets.)

Innovation #4: Lever simple machine. There are a number of classes of simple machines, of which the lever is perhaps one of the oldest. It allows people to amplify their mechanical effort. Hammers and plows mean that instead of the effort of one person digging with hands or tools, now there is mechanical advantage. Farmers can plow deeper and throw farther and with more force. Archimedes is famously said to have stated, "Give me a place to stand with a lever and I will move the whole world." In fact, the concept of a lever has moved the whole world since its invention.

Innovation #3: Inclined plane simple machine. Don't just think ramp, think blades, wedges, chutes, slides, and screws. Chopper cores unearthed at the Olduvai Gorge in East Africa that are 1.9 million years old show a clear effort to manufacture. They were used for chopping and scraping hides as well as for hunting. That technology was brought forward to the high art of the Clovis arrow point and the higher still art of Archimedes' screw water pump, which permitted hydraulic irrigation by pumping water up out of canals and rivers and into irrigation ditches with a simple turn of the screw.

Innovation #2 is the **taming of fire.** Fire has been around a long time, often caused by lightning strikes. But being able to make fire on demand, or first being able to capture it from the wild and preserve and use it as you wish, permitted humans to live in colder places, work after dark, inhabit places that were dark and perhaps dangerous, scare off animals at night, and cook food in order to preserve it. Fire-starting technologies are tremendously tough to master, which probably also meant more specialization of labor as humans began to use simple technologies like the fire plow, the fire

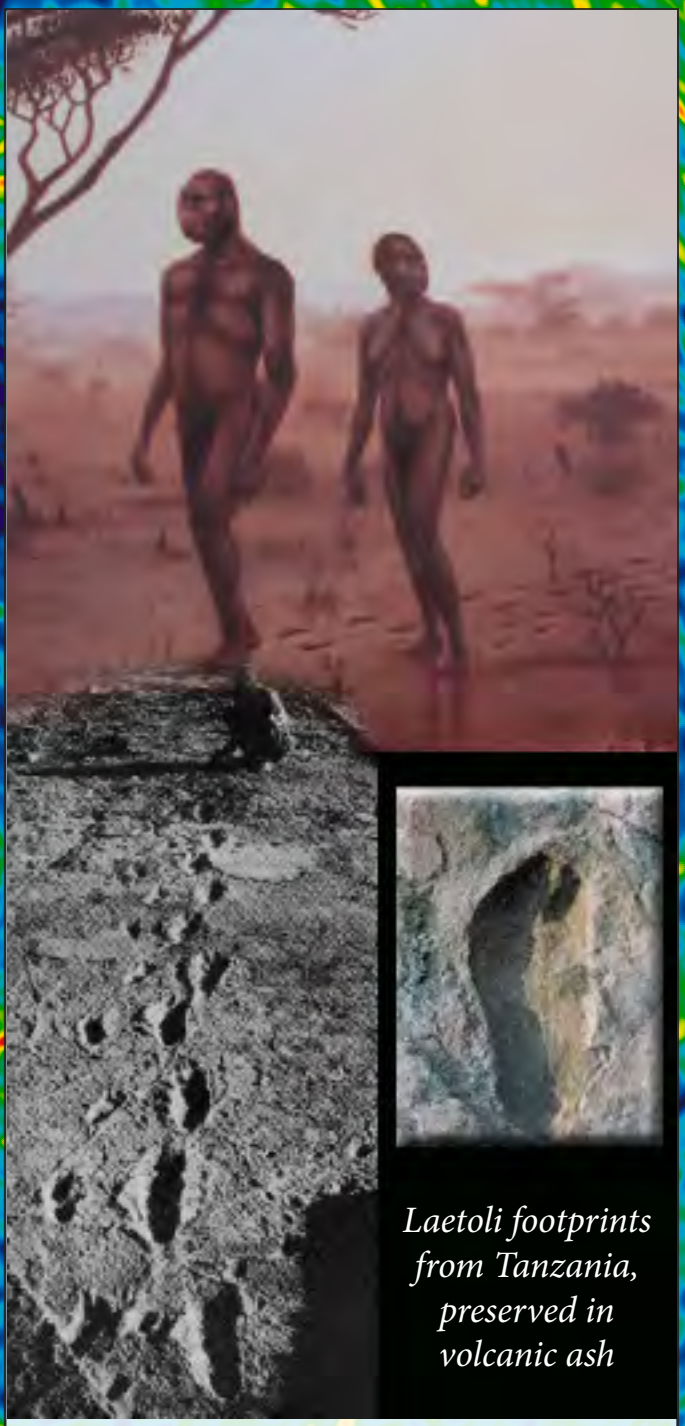
drill, and the smudge bundle, otherwise known as the cigar.

Innovation #1 is spoken language—true semantic, syntactic, phonetic language. This idea allowed humans to transmit information about the world from one person to another. It underlies all cooperation, the economy, and clan relationships. Spoken language is the most important innovation we have ever come up with.

However, I reserve the right to add an Innovation #0 (since I work with computers, and programmers start counting from zero, not 1). Innovation #0 in my view is one that outshines and underlies every other innovation we have discussed. That is the concept of intentional pedagogy. This is perhaps the last thing in that great long list of what separates us from the "lower animals," a phrase Darwin rejected. It's the idea that humans can intentionally transmit culture and generalize knowledge from the specific instance to that which is teachable, and then intentionally give that knowledge to another person across time and space. From telling your child that the fire is hot and not to touch it to the internet itself, intentional teaching is the most important innovation of all time.

"The systematic use of teaching to ensure the learning of skills and acquisition of knowledge by others is evidently a peculiarity of the human species." "Humans are remarkable among animals for the way in which they teach their young." S.A. Barnett suggested that homo sapiens, the understanding man, is perhaps not the right taxonomy for our species, that really what we should be called is homo docens, teaching man.

So what didn't make the list? Lots of things, for reasons that I hope you will understand and then vehemently disagree with. Everything from theories of disease, inoculations, and antibiotics to guns and gunpowder, and plastics to democracy to even the idea that there is such a thing as an idea, in my estimation couldn't make the cut of the metric I set forth earlier: impact on lives times number of lives. Others have had different concepts of what innovation means and what innovations are truly important. My hope is not that I have it right, but that readers will help me get it more right with your comments, questions, emails, or simply throwing it wrapped around a rock through the transom.



The famous Laetoli footprints made by hominids some 3.6 million years ago suggests two hominids strolling along together. It is tempting to think the two were chatting as they meandered, but this is most likely far too early a date for syntactical language.