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Material cultures are the result of human ingenuity and aim at a purpose: a very basic notion of "technology". They have surrounded the birth of human babies for more than three million years, much earlier than previously thought. In 2015, the discovery of an enigmatic lithic industry was announced at the Lomekwi 3 site on the western shore of Lake Turkana in Kenya, surprisingly dated to 3.3 million years ago, that is, more than half a million years older than the first known fossil belonging to the genus *Homo.* We have to rewrite the textbooks because it is unlikely that *Homo habilis* was the first human to build and manipulate tools (Harmand *et al.*, 2015). He no longer deserves his surname. Lomekwi's tools are rudimentary and often unfinished, but already diversified: they are a lithic "industry" in all respects, not a failed experiment of occasional creativity. We do not know which technologist hominin made them: in those regions in Africa, at that time, australopithecines of the *A. afarensis* species (like Lucy) and their *Kenyanthropus* cousins circulated. They had a brain that was a third of ours.

Our brains develop for two thirds after birth. Thus, the experiences, the care we receive, the family and social context in which we grow, the encounters that happen to us, the games with friends, what we learn by social imitation, and so on, literally carve our brains (Dehaene *et al.*, 2015). Therefore, in the past, the tools and technological (bodily and mental) prostheses that we learned to use, that surrounded us since we were born and that perhaps we ourselves contributed to invent or improve, shaped our brains (Wrangham, 2009). Fire, cooking food, group life have transformed the environment around us, making it more permissive, relaxing natural selection, so allowing the affirmation of costly adaptations such as neoteny (the retention of juvenile traits in adults, our developmental secret) and articulated language.

Long after, when the last glaciation ended 11.700 years ago, after a long period of trials and errors (intuitive selection of plants for feeding and self-medication, flour production, and so on), some populations of *Homo sapiens* learned to systematically domesticate plants and animals in several regions of the globe. Today, we think of agriculture as the domain of the "natural", but actually it was the largest technological experiment in the engineering of terrestrial ecosystems ever done. Some plant and animal species started to produce goods useful to humanity, as of course they would never have done. Artificial selection has radically transformed them, morphologically and genetically. Nevertheless, from their point of view, domesticated plants and animals have cleverly used us humans as vehicles of diffusion. As a result, ecologically and geologically speaking, the Earth has never been the same via technologies. The Anthropocene is an old story.

We change the world, and the world changes us

What do we learn from these discoveries about the long natural history of technologies? Firstly, that the different human species (five human species inhabited the planet up to 50.000 years ago – Pievani, 2018) have been immersed in eco-cultural and technological niches for a long time, for more than three million years. We took advantage of the natural phenomena that surrounded us: the properties of minerals, fire, flesh and bones of the preys, then of domesticated plants and animals, and then metals, water, wind, and coal in the last two centuries. We invented technologies (including writing) that have filled our ecological niches and our babies have become "native" from time to time with new technologies. Therefore, technologies have contributed to sculpt their brains differently. The eco-cultural niches so modified fed back, retroactively, on human populations modifying them on the social, cognitive but also genetic level. In short, the genus *Homo* evolved in symbiosis with its technologies. It is no longer correct to say that there has been an "evolution of technologies", as if they have changed on their own. Technologies intrinsically and closely co-evolved with us, and the process is still going on.

The expansion of Middle Eastern farmers towards Europe began around 9 thousand years ago: first in Anatolia, then in the Balkan Peninsula, then again in Central and Western Europe. Together, grain cultivation and the domestication of animals obviously arrived in Europe. That is, both humans with unprecedented behaviours and new technologies arrived (Cavalli-Sforza, Pievani, 2011). The European ecological niche changed because many animals that produce meat and milk, and interact with humans, were now around. Molecular biologists have recently discovered that 7500 years ago – perhaps in the Hungarian plains or in northern Europe – a genetic mutation spread in some groups of shepherds and farmers, which delayed the shutdown of the lactase enzyme used by babies to break down and digest milk. The mutation allowed carriers to digest first the milk derivatives (which contain less lactose) and then directly the nourishing fresh milk even in adulthood, offering them considerable adaptive advantages. The mutation spread successfully, although there is always a percentage of the population that does not possess it (still today).

What happened exactly in evolutionary terms? A cultural and technological change (that is, breeding animals) modified the human ecological niche, altering the selective pressures that acted on the human groups of the time, so favouring the success of a certain genetic mutation. Technology came first, then genetics. It seems evolution upside down: a cultural change led to a genetic change, and not vice versa as we usually think. The phenomenon

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repeated elsewhere, in West Africa and the Arabian Peninsula, with similar effects. In some regions (for example in the Far East, Australia, and the Americas), quite no one in the native populations is able to digest milk. The mutation never came. A planetary map of lactase enzyme activation clearly shows that what we are today, even at the genetic level, depends on our long coevolution with technologies (Curry, 2013).
Between biological evolution and technological (cultural) evolution, there are many analogies and differences in terms of mutations (innovations), strategies of diffusion (fashions) and inheritance (traditions), and selective processes (Cavalli-Sforza, Feldman, 1981). However, it is in the constructive relationships between individuals and environments that a strong connection between the two emerges. Cultural changes can feed back on our biology and modify our genome (Laland, 2010). This also applies to alcohol metabolism after the invention of fermentation technologies for producing beer and wine; to the recent, continuous availability of fatty and sugary food in relation to the epidemic diffusion of obesity; to the maladaptive effects on our immune system and microbiotas of our daily lives in industrial and urbanized environments. The domestication of fire itself (a new technology) induced humans to adapt to eat cooked food, recursively. Now our digestive system depends on cooking. Genetic changes having cultural changes as drivers are defined *gene-culture coevolution* (Fisher and Ridley, 2013), but it is easy to see that in all the cases mentioned above specific technologies are involved, so the gene-culture coevolution is also, and more precisely, a *gene-technology coevolution.*

Humans, the great builders of their niche

"Niche construction" is the general term for the co-evolutionary pattern in which organisms do not just respond to selective pressures imposed by the environment, but also actively contribute to modify the environment itself, therefore modifying the frame of selective pressures that then feedback on them (Odling-Smee et al., 2003). Niche construction is an ambivalent process: it has given us great evolutionary successes and prosperity (even if not for everyone), but it can turn into an evolutionary trap if the environment is transformed and altered too quickly. Being builders of your own ecological niche (eco-technological in our case) means altering the ecological niche of others. Some much known human technological activities (namely five: deforestation; spread of invasive species; agricultural and industrial pollution; overpopulation; intensive hunting and fishing) are causing the Sixth Mass Extinction of biodiversity, as serious as the five major catastrophes in the paleontological records (Pievani, 2015). This time *we* are the asteroid.
Only a mixture of greed, short-sightedness and insipidity can explain a behaviour that is counterproductive even on a purely economic and anthropocentric level. The depletion of ecosystems guarantees immediate profits to a predatory market but will present us with a very expensive bill when we have to pay the "ecosystem services" that we receive for free today (water cycle, air cleaning, soil fertility, pollination, and so on). What is climate change if not a global (and risky) niche construction process? Technologically, we bring fossil fuels to the surface, refine and burn them. We produce tons of carbon dioxide per capita by heating houses and using old-fashioned means of transport. We alter the composition of the atmosphere and the extent of the greenhouse effect. We pollute the waters and change the acidity of the oceans. We empty mountains and divert the course of rivers.
In other words, climate change on the evolutionary scale is a global niche construction process in which a single species alters the ecological parameters and biogeochemical cycles of the biosphere by obliging the other species to adapt in the short term. However, we are also obliging ourselves to re-adapt on the medium term to higher average temperatures, to more energy in the planetary networks, higher levels of the seas, with growing masses of environmental refugees forced to move from their homeland. Not surprisingly, "adaptation" (an evolutionary term) has become the key word of the recent International statements on climate warming. Furthermore, many observers point out that facts and numbers are not enough to be truly convincing of what is happening: climate change is a counter-intuitive phenomenon (too large, slow, non-linear) for our minds and we could be embroiled also in a cognitive trap (Diamond, 2005; Pievani, Meneganzin, 2020).

Climate change natives

Niche construction also maps very well the processes of biotechnological "symbioses": cyborg grafting (neuro-chips); biomimetic technologies; synthetic biology (borrowing a technological metaphor to produce microorganisms with computer-engineered genomes); expanded DNA (De Biase and Pievani, 2016). Niche construction processes also involve the integration of heterogeneous dynamics with unpredictable loops of interdependence. For example, converting large portions of territory to produce bio-fuels (new technology, apparently green) initially seemed a good idea; actually, it was bad for environmental impact, land use and global price dynamics. Side effects and interconnections generate unexpected problems, to which Homo sapiens responds with new technological research (i.e. production of biofuels without land consumption, for example using algae).

These recursive dynamics clearly show how, despite the possible evolutionary and cognitive trap, any catastrophic techno-skepticism is inconclusive. If the nineteenth-twentieth-century technologies are at the origin of most of the aforementioned problems, the damages are not inherent to technology itself but to its uses. Technology itself is and will be an essential part of the solutions thanks to innovation, energy efficiency, and all the eco-sustainable alternatives that will come to mind for the humans of the future.

Those humans of the future will be "climate change natives". Niche construction processes also explain particularly well the phenomenon of being "native to a technology". The technological ecosystem in which we are born provides the basic selective pressures (cultural and social) that influence cognitive and social development. The human brain always seems the same, but growing in a new technological landscape is like being born in a different environment that redefines our relationships with reality. Our technologically re-alphabetized brains are biologically – not just culturally – different from those of the previous generations (Pagel, 2012).

Thus, we can hope that "climate change natives" will find solutions that we, as "climate change immigrants", cannot even imagine. Right now, all over the world, a swarm of creative girls and boys, engineers, designers, investors and entrepreneurs, inventors and researchers is building the next horizon of the technosphere, which is still unknown to us. Who could have imagined the serendipic discovery of gene editing ten years ago? Now, who can predict what we will do with these biotechnologies in ten years?

In evolutionary terms, the so-called "post-human" is a nonsense: evolution teaches us that what will come after the human will still be something human, something still invented by the same *Homo sapiens* the African. Old dichotomies lose their meaning: uncritical techno-enthusiasts VS unlimited techno-sceptics; naturalness VS artificiality; revolution VS continuity; individuality VS collective superorganism. Co-evolution means responsibility: we are actors who, with their choices, actually build the eco-technological niche of the future, which will then transform us and into which our grandchildren will be "native".

Unpredictable tinkering

We invent technologies, which change the eco-cultural niche (social, economic, of the imaginary), which again changes us through new selective pressures. Technology arises from a need or an opportunity, but then generates other desires and opportunities (think about the auxiliary needs induced by the automotive or digital industry) (Basalla, 1988). Technology calls technology, and in some respects we are its productive and reproductive organs (Kelly, 2010; 2016). Small frequent changes can have apparently negligible but cumulative niche construction effects; others have intermediate effects; others have perhaps a modest onset, and then explode in rare large-scale eco-technological upheavals. The technological ecosystem evolves together with its actors. We need an "ecological theory" of techno-evolution, not only in the sense of preserving the natural environment, which is also a crucial component of the model, but in the sense of understanding the ecological dynamics in terms of inter-dependencies and co-evolutions among artefacts, inventions, projects and human societies.

Technologies arise from a request, from a material or immaterial need, but their exuberant diversity is not reducible to the needs of the moment: it goes further and transcends them. Technological innovation never starts from nothing, but existing technologies are recombined and hybridized, reorganizing them through new design and usage principles (Brian Arthur, 2009). Natural selection works in the same way, struggling and finding trade-offs with the constraints of the previous structures. We start from the available material and recombine it, we move from pre-existing constraints and modules, in a continuity of change fuelled by the creative and sometimes revolutionary reuse of what already exists. This evolutionary tinkering is the basis of both biological evolution and human techno-evolution (Pievani, 2019). The historical origin and current function of an organ (as well as an artefact) do not necessarily coincide.

We call "exaptations" those functional shifts. In the history of technologies, it is rare to find an invention that maintained the same uses and functions originally envisaged by its creator (Gould, 2002). Thomas Edison designed the phonograph for anything but playing recorded music. The same is true for radio, transistor, laser, internet, and GPS. Not to mention the multiple reuses and extensions that mobile phone technology is having, invading our days with its trills. Every technology, when it is born, enters into an ecology of other already existing technologies and changes the pattern of relationships among them (Kauffman, 2000).

Our brain is a compendium of exaptations: its neural components, more or less ancient, were born in relation to certain survival functions and then were co-opted to do something else. Hence, with a brain born 200 thousand years ago in Africa, but unusually plastic, today we learn to read and write, that is, to produce technologies and to carry out tasks for which certainly our brains have not evolved (Tattersall, 2013). For a mobile and expansive species like ours used to living in unstable and heterogeneous ecosystems, as well as to constantly migrate in search of new possibilities, flexibility, adaptability and plasticity are the primary survival strategies. Such a plastic brain is able to establish a dynamic of close co-evolution with the technologies it produces, and that fill its eco-cultural niche.

The cemetery of wrong predictions is expanding. Today we are less and less plunged into the category of necessity, and increasingly into that of possibility. Imagining a future scenario already means influencing the future. The same large bipedal mammal, with the same brain size, that 100.000 years ago scrambled with sticks and chipped stones, today drives a spaceship, builds robots that explore Mars' surface and invents nano-technological wonders such as graphene. This residual African twig of the genus *Homo* has walked a long way, presumptuously giving itself the surname "sapiens". 100 thousand years seem a lot, but actually, it is a little more than 4000 human generations. Human techno-evolution is only in its infancy.

REFERENCES

Basalla, G. (1988), *The Evolution of Technology*, Cambridge University Press, Cambridge, United Kingdom.

Brian Arthur, W. (2009), *The Nature of Technology*, The Free Press, New York.

Cavalli-Sforza, L.L. and Feldman, M. (1981), *Cultural Transmission and Evolution*, Princeton University Press, Princeton (Nj).

Cavalli-Sforza, L.L. and Pievani, T. (2011), *Homo sapiens. The great history of human diversity,* Codice Editions, Turin.

Curry, A. (2013), "The milk revolution", *Nature*, Vol. 500, pp. 20-22.

De Biase, L and Pievani, T. (2016), *Come saremo. Storie di umanità tecnologicamente modificata*, Codice Editions, Turin ("How we will be. Stories of technologically modified humanity").

Dehaene, S. *et al.* (2015), "Illiterate to literate: behavioural and cerebral changes induced by reading acquisition", *Nature Reviews Neuroscience*, Vol. 16, pp. 234-244.

Diamond, J. (2005), *Collapse. How Societies Choose to Fail or Succeed*, Penguin Books, New York, USA.

Fisher, S.E. and Ridley, M. (2013), "Culture, Genes, and the Human Revolution", *Science*, Vol. 340, pp. 929-930.

Gould, S.J. (2002), *The Structure of Evolutionary Theory*, Belknap Press-Harvard, Cambridge, Massachusetts , USA.

Harmand, S. *et al.*, (2015), "3.3-million-year-old stone tools from Lomekwi 3, West Turkana, Kenya", *Nature*, Vol. 521, pp. 310-316.

Kauffman, S. (2000), *Investigations*, Oxford University Press, Oxford.

Kelly, K. (2010), *What Technology Wants*, Penguin Group, New York, USA.

Kelly, K. (2016), *The Inevitable: Understanding the 12 Technological Forces That Will Shape Our Future*, Viking, New York.

Laland, K.N. *et al.* (2010), "How culture shaped the human genome: bringing genetics and the human sciences together", *Nature Reviews Genetics*, Vol. 11, pp. 137-148.

Odling-Smee, J., Laland, K.N and Feldman, M.W. (2003), *Niche Construction. The Neglected Process in Evolution*, Princeton University Press, Princeton (NJ).

Pagel, M. (2012), *Wired for Culture*, Norton, New York, USA.

Pievani, T. (2015), "Earth's Sixth Mass-Extinction Event", in "Science Direct", *Elsevier - Online Reference Database: Earth Systems and Environmental Sciences*, online 9 November 2015.

Pievani, T. (2019), *Imperfezione. Una storia naturale*, Raffaello Cortina Editore, Milano ("Imperfection. A Natural History").

Pievani, T. and Menaganzin, A. (2020), "Homo sapiens: the first self-endangered species", in Roque, A.C. Brito, C. and Veracini, C. (Eds.), eds., *Peoples, Nature and Environments: Learning to Live Together*, Cambridge Scholars Publ., Newcastle upon Tyne (UK), pp. 10-24.

Tattersall, I. (2013), *Masters of the Planet*, Griffin Publ., New York, USA.

Wrangham, R. (2009), *Catching Fire: How Cooking Made Us Human*, Basic Books, New York, USA.