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A New Definition of "Artificial" for Two Artificial Sciences

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Abstract
In this article, I deal with a conceptual issue concerning the framework of two special sciences: artificial intelligence and synthetic biology, i.e. the distinction between the natural and the artificial (a long-lasting topic of history of scientific though since the ancient philosophy). My claim is that the standard definition of the "artificial" is no longer useful to describe some present-day artificial sciences, as the boundary between the natural and the artificial is not so sharp and clear-cut as it was in the past. Artificial intelligence and synthetic biology, two disciplines with new technologies, new experimental methods, and new theoretical frameworks, all need a new, more specific, and refined definition of (the) "artificial", which is also related to the use of the synthetic method to build real world entities and in open-ended (real or virtual) environments. The necessity of a new definition of the artificial is due to the close relationship of AI and synthetic biology with biology itself. They both are engineering sciences that are moving closer and closer, at least apparently, towards (natural) biology, although from different and opposite directions. I show how the new concept of the artificial is, therefore, the result of a new view on biology from an engineering and synthetic point of view, where the boundary between the natural and the artificial is far more blurred. From this, I try to formulate a brand-new, more useful definition for future understanding, practical, and epistemological purposes of these two artificial sciences.

Keywords Artificial intelligence · Synthetic biology · Artificial-natural · Biology · Synthetic method

1 Introduction

Special sciences challenge the whole of human knowledge from different perspectives. They deal with specific problems of a particular domain by increasing overall knowledge, which is the sum of scientific knowledge coupled with common-sense knowledge about everyday life. This has given rise to new theoretical issues concerning the conceptual framework underlying the relationship among different fields of study. This last aspect raises many typical problems addressed in the philosophy of science, which in the course

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of the last century has changed and broken away from a general philosophy of science into a philosophy of special sciences. Moreover, these kinds of conceptual problems are growing insofar as special sciences increase their amount, so that, for example, the philosophy of medicine, cognitive science, or engineering sciences have added to the more classical philosophy of physics, biology, or mathematics.

In this article, I will tackle a conceptual issue concerning the framework of several sciences: the distinction between the natural and the artificial, a long-lasting topic of history of scientific thought starting with ancient philosophy. My claim is that the standard definition of the "artificial" is no longer useful to describe some present-day artificial sciences, as the boundary between the natural and the artificial is not distinct and clear-cut as it was in the past. I think that some new sciences, with new technologies, new experimental methods, and new theoretical frameworks need a new, more specific, and refined definition of (the) "artificial" to use. I especially refer to artificial intelligence (AI) and synthetic biology, two relatively recent disciplines exploiting the synthetic method with the aim to build real world entities and in open-ended (real or virtual) environments. The necessity of a new definition of the artificial is due to the close relationship that AI and synthetic biology have with biology. They both are engineering sciences that are trending towards (natural) biology from different and in a sense opposite directions. It is interesting to notice, however, that from a different point of view the movement of AI and synthetic biology toward natural biology highlights the big distance of these two sciences from biology itself, and as a consequence their distance from natural world of living being in their artificiality. The new concept of the artificial is, thus, the result of a new view on biology from an engineering and synthetic point of view, where the boundary between the natural and the artificial is far more blurred, also as a consequence of this twofold situation.

In the history of thought, we may find a similar situation in Leibniz's attempt to define the difference between artificial and natural machines, the latter remaining machines to the least of their parts, according to a disputed expression by Leibniz himself (Nachtomy, 2011). In debating this hard subject and in accordance with his definition of natural machines, Leibniz traced back the distinction to the differences between aggregates and unities, which followed his metaphysics. The long-lasting debate on Leibniz's conception of natural machines is not within the scope of this paper, but Leibniz's attempt attests to the interest toward the artificial-natural distinction from a "natural" point of view (that of natural machines) in a largely pre-biological age as well as the difficulty to deal with these ideas.[1]

In the following sections I address the issue of the artificial in AI and synthetic biology. In Sect. 2, the focus will be on the ancient notion of the artificial as an imitation of nature and some present-day variations in chemistry and in the sciences of the artificial. In Sect. 3, I deal with AI and its biological aspects, especially concerning the recent approaches and techniques. In Sect. 4, I tackle the artificialness of synthetic biology. Then in Sect. 5, I try to develop a new, more specific definition of the artificial, which I call the Artificial, to draw some conclusions in Sect. 6.

[1] Both for Leibniz and for those who have discussed his ideas on it. To provide just one example of a present-day interpretation of Leibniz's words about natural machines, according to Nachtomy they "are indivisible units in the sense that they are defined and informed by a single rule of generation, compatible with their having an infinitely complex structure such as an infinite series or a fractal-like structure" (Nachtomy, 2011: 77).

2 Does the Artificial Imitate the Natural?

Far from having a clear and once-and-for-all well-defined distinction between the natural and the artificial, yet, we have an intuitive idea of it. We take it for granted, but to describe in detail such a distinction is difficult. The reason why things are like this is most likely connected with the cultural evolution and the changes in our relationship with nature, knowledge, and science. Nevertheless, this distinction is not relevant just for cultural purposes. It does concern and affect our view of reality and attitudes toward specific scientific and technological outputs. The distinction between the natural and the artificial, therefore, is part and parcel of our research and scientific activities, because it allows the establishment of objects for different scientific fields as well as methods and methodologies to investigate the domains of interest. This has been always true. Every period has had its own conception of the natural and the artificial that has shaped the form of and relation with science and technology.

If from a historical point of view, the relationship between the natural and the artificial can be characterized as an evolving polarity (Bensaude-Vincent & Newman, 2007), present-day disciplines such as computer science and biotechnology compel a reappraisal of this distinction regarding both the conception of it, which stems from previous time periods, and the commonsense view about the natural and the artificial. We may say that, like many other polarities, it should be considered as a distinction by degree and not a black-or-white distinction. The issue, however, is not so simple, as the requirements for a sharp separation are due to decisions made in specific situations concerning medical, biological, health, legal, political, and ethical aspects. A clear-cut definition of what is artificial and what is natural is an epistemological question, which should consider scientific, social, and human aspects all together. This is particularly true for two scientific disciplines that connect scientific, technological, and humanistic traits well: AI and synthetic biology.

In some passages of *Physics*, Aristotle distinguished between two kinds of arts, meaning that art is made by human beings in general and in contrast to what is natural (actually and incidentally, this is the etymology of the word "artificial"). The two kinds of arts from Aristotle are: (1) arts imitating nature; and (2) arts leading to a state of perfection a particular natural situation step by step.[2] The second kind is, for example, the case of a physician. This distinction is interesting and follows a more common definition of "artificial" by Aristotle that refers to the capacity of human beings to impose a form and a structure on something natural. For example, certain materials from nature used to make a thing without an innate impulse to change.[3] This second definition is well-known and appears to be more suitable to speak about the artificial and the natural as regards AI and synthetic biology.

On the one hand, imitation has had a crucial role at the starting point of AI and when Turing spoke about the imitation of human intelligence initially he did so by programming a paper machine that was able to play chess (Turing, 1948). Secondly, he spoke about it through a more elaborate linguistic interaction with a different type of machine, a digital computer (Turing, 1950). In both cases, the machine has to imitate human intelligence by laying aside other human, more bodily, capabilities. On the other hand, imitation and similarity are crucial in other branches of AI, such as robotics, humanoid robotics, and

[2] See the Book II, chapter 8, of Aristotle's *Physics*: «generally art in some cases completes what nature cannot bring to a finish, and in others imitates nature. If, therefore, artificial products are for the sake of an end, so clearly also are natural products.» (Aristotle, 1991: 32).

[3] See the Book II, chapter 1, of Aristotle's *Physics*.

virtual-human technologies. The *uncanny valley* hypothesis (Mori, 1970), for example, is built on the notion of similarity between human beings and robotics. The more a robot imitates a human being, the greater the comfort of the human being with it will be, but this is just the first part of the hypothesis. The second part of the hypothesis, which is the core of the hypothesis, indicates that there is a range, precisely the uncanny valley, on the curve that describes a growing similarity between an artificial humanoid artifact and a human being, for which human beings, are far from feeling an emotional bond in relation with a humanoid artifact, because of increased humanoid traits. Beyond this range the human feeling toward a humanoid artifact develops into positive feelings that are characterized by comfortable emotions. Many different interpretations have been suggested to explain this phenomenon,[4] but one issue related to imitation is crucial: the highest point of the curve, beyond the uncanny valley, corresponds to that of a healthy person. This could not be other than an idealized concept of a human being; however, it is a perfect human being that is more human than most other humans (Dumouchel & Damiano, 2017). This recall jointly the two aspects of the artificial in the Aristotelian definition from chapter 8, book II of *Physics*. Perfect similarity removes the uncanny so that it vanishes, which gives rise to questions about the relationship between the natural and the artificial in AI and synthetic biology for which the artificial is an imitation of the natural. For example, the following questions can be asked: to what extent the imitation defines artificiality? Is there a limit of resemblance or replication beyond which something artificial becomes natural? Is this boundary reachable by human theoretically and technologically? These questions generate further philosophical inquiries as follows: to what extent the distinction between the natural and the artificial is frightful for human beings? And if so, what is the relationship with specific disciplines especially devoted to replicate some aspects of, or the whole, human being as AI and synthetic biology? What is the impact on research within these disciplines? And on the definition of their specific object? What are the ethical or legal consequences for scientific research and, at the same time, for society? All these issues are connected with the core of scientific investigations by disciplines at the frontier between the artificial and the natural, and which try to attain the natural starting from the artificial.

Even though the imitation is not a general feature of the artificial, it is present also in disciplines more connected to the biological world. For example, since the 19th Century, chemistry has ventured on the production of substances that were yielded only from other living beings (Brooke, 2007) with many of successful attempts leading to the foundation of organic chemistry. The developments of inorganic chemistry played an important role in the improvement of the process of synthesizing compounds such as the different kinds of plastics, an improvement that has had as a result the strengthening of the view that "synthetic" can be considered as a synonym of "artificial" (Bensaude-Vincent, 2007). The general methodology of synthesis as the method to create new compounds, materials, and substances produced by living beings has been a fundamental step on the path that leads to new dimensions for the artificial, i.e. one that is more consistent with our present-day view. Yet, also the methods of synthesis brought inside themselves the double character of the notion of the artificial: (1) the imitation of something; and (2) the creation of something that is an improvement by (re)combining, transforming or recreating natural elements or products. All these activities are usually considered within the scope of biomimetics and the wider range of bio-inspired technologies. What is interesting is that biomimetics or

[4] For example, see Kätsyri et al. (2015) for a discussion on the development of the original hypothesis in the light of more recent empirical evidence.

biomimicry is a relevant part of synthetic biology (Church & Regis, 2012), which, from this point of view, can be seen as the end of the path that leads from the notion of compound synthesis to the synthesis of the living. The synthesis of biological stuff in synthetic biology, however, is not just an imitation of nature. Rather, it is that *and at the same time* it is creation of new biological devices, parts, and whole systems which are compound by biological materials or chemical substances forming the basis of biological systems. The distinction between the natural and the artificial becomes blurred. Where is the boundary here? What should we define as natural and what as artificial, speaking about products of biological synthesis? Rules used by patent systems may set a conventional boundary (Bensaude-Vincent, 2007), but they are too narrow for epistemological and research aims.

3 The Boundary Sciences of the Artificial (Intelligence)

My first claim about the two sciences I deal with in this article is that AI and synthetic biology are complementary disciplines and interconnected from the standpoint of the artificial. Firstly, to see to what extent these overlap and in which sense, I run through AI by dealing with its definition, aim, and scope. Then, I end by speaking about its "synthetic-ness". Next, I will follow a similar path for synthetic biology, which is to identify its specific and peculiar artificialness.

A clear-cut definition of AI is hard to achieve, because it has had a history with many changes of perspective, aim, objects, and approaches. This is also true for the artificialness aspects of AI. In the third edition of a well-known textbook on AI (Russell & Norvig, 2009),[5] they pinpointed eight definitions of artificial intelligence along with two dimensions as follows: (1) reasoning and behavior, and (2) human performance and rationality performance. The first dimension is related to the distinction between thought processes and the "laws of thought" on one hand, and intelligent action on the other. This is the traditional distinction between a cognitive AI and an engineering AI. The second dimension is more interesting insofar as it underlines the difference between an AI as an imitation of actual intelligent human performance and an AI whose ultimate aim is to achieve an ideal intelligent (specific or general) performance in accordance with an idea of "perfect" rationality,[6] i.e. meaning to do the "right thing", given what the it knows, as Russell and Norvig state. This second distinction is, again, another version of the distinction between an artificial as nature imitation and an artificial as an improvement on something natural. In AI, these two different attitudes toward the aim of artificialness are particularly manifest.

The four cases are just an abstraction, but they encompass virtually every position from the relevant literature (Bringsjord & Govindarajulu, 2020). This distinction, however, is fundamentally based on two "natural" concepts: 1) the nature of human; and 2) the nature of rationality. In other words, it does not focus on the artificial. This is generally a

[5] The handbook has had four main editions in 1995, 2002, 2009, and 2020. This testifies for the fast evolution of the discipline, and the necessity of a constant significant updating.

[6] The distinction between a perfect rationality and a bounded rationality is at the center of AI origins, at least as regards the human though simulation and modeling. See Simon (1957) for the beginning of the debate on rationality.

mainstream of AI definition, as the core of the label "AI" is more often the intelligence (of human beings and/or intelligent systems) and not the artificial.[7]

In *The Discovery of the Artificial*, Cordeschi claimed that the two main tendencies of AI are present from the beginning of the discipline and underlined that they are related to two different uses of the term "heuristics". In its first sense this term refers to "the most detailed simulation possible of human cognitive processes"; whereas, in another sense the term refers to "the possibility of obtaining the most efficient performance possible from programs, by allowing also for typically non-human procedures, such as those where the computer can excel" (Cordeschi, 2002: 190). This characterization shifted the stress from intelligence towards the artificial, if we consider heuristics as the most general whole of methods to achieve intelligence in an artificial way, being human-like or non-human-like. The tension between these two AI tendencies has a long story in literature and research, which is still present in contemporary approaches to AI. The stress on heuristics, however, corroborated the view according to which the artificial of AI is not merely a simulation *on a computer*, but a simulation on a computer of *methods and procedures* that allow for the creation of something that is definable as intelligent by bypassing the computational limits of brute force programming. It is not important if these methods and procedures are the same as those used by human being. This could be important, previously and currently, for researchers interested in studying and understanding, through using an AI approach, human cognition. The artificial in AI emerges already in early AI research as a software issue rather than a hardware issue, even though, as Cordeschi pointed out, heuristics and experimentation with heuristics in AI "soon took directions other than that of the selective search in the state space", which is one of the standard in automated problem solving, "giving rise to an extremely varied range of proposals, projects and experiments" (Cordeschi, 2002: 191). Likewise, it is also relevant that the "heuristics-oriented" way of AI is the main core of the synthetic method, which is the method of model building to construct artifacts that embody the shared principles with organisms - artifacts that "would not simply mimic the behavior of organisms" (Cordeschi, 2002: 248).

The fundamental aim of the synthetic method is to test and validate theories of organism behavior from sensorimotor to high-level cognitive aspects. According to such a method, an artifact is built and its behavior is analyzed to see if the mechanism controlling the artifact is somehow and, in some respects, the same as the mechanism controlling the living system to which it is inspired. This is valid for hardware artifacts, such as robots, but also for software artifacts, such as intelligent systems, AI classical programs, neural networks, or even computer simulation of hardware artifacts, like robot computer simulations (Datteri & Tamburrini, 2007; Cordeschi, 2008). The synthetic artifact, in the sense of the synthetic method, must have some specific constraints the are relevant to consider it as a model of a theory, or a part of theory, which could be used to explain the behavior. Only if the constraints are relevant and useful in making the artifact, in some sense, to model the system for which it is a model of, the synthetic method could verify, corroborate, or reject the theory on which the artifact is built. The meaning of synthetizing an artifact strongly relies on the constraints chosen for modelling the living system, whose behavior should be

[7] Russell too provides an example of this trend by focusing on rationality (Russell, 1997) as well as he is an example of an author assuming we already know what an *artificial* system is (Bringsjord, Govindarajulu, 2020).

explained.[8] The connection with living systems is a result of the cybernetics roots of AI, but it is also related to a sense of intelligence that is connected with living systems through the notions of autonomy and survival that have been more and more important in the multifarious development of AI. It is not possible going further on the analysis of the notion of intelligence—in fact, it is a long-lasting debate in philosophy of AI and in AI in general—as the focus of this article is the artificialness of AI.

Even though the synthetic method referred to the disciplines of the artificial appears as the best candidate to support the AI trend of human cognitive processes simulation, by allowing to use computer simulations as models with relevant constraints to be cognitive models, this method is not limited to this tendency or to the modelling of purely traditional cognitive capabilities, such as (abstract) reasoning, problem solving, or memory retrieval. In the last 40 years, AI has become a broad and many-sided field of study from a theoretical and an applied point of view. These days machine learning, neural networks, non-humanoid and humanoid robotics, deep learning, search optimization algorithms, voice assistants, and even the Internet of Things fall within the range of AI. Human cognition modelling and efficient artifacts and systems in intelligence behavior are still two general categories of all AI products. In addition to the aforementioned, even though computer simulation, the software side of AI, is a mainstay of AI for understanding the world (Weisberg, 2013) of the human mind or cognition, the hardware-side of AI has gained renewed relevance, as in the cybernetic period before AI birth. This does not mean that hardware aspects of AI artifacts could not been simulated, as in fact they are in virtual robotics, robot simulator tools, or a virtual environment of multiagent systems (Shoham & Leyton-Brown, 2009). The more recent - embodied, embedded, environmental, and hardware-side - AI trends denote, however, a greater and radical influence of biology on AI.

Speaking about a biological AI, such an influence is not just identifiable in the big part of AI known as Artificial Life or ALife (Aguilar et al., 2014), which is especially devoted to the study of living systems and natural life through computer simulations and robotics.[9] A biological influence on AI has led to the creation of systems having something recognizable as biological at some level. Examples of this include neural networks, evolutionary algorithms, cellular automata, and all the systems of bio-inspired AI (Floreano & Mattiussi, 2008). Among these approaches, one deserves particular mention that concerns the integration between biological (neuronal) tissues and in silico circuits: neuromorphic computing. Starting from the seminal research on neuromorphic electronic systems by Carver Mead (1990), this approach showed a new direction of a neural network based AI approach, which has a deeper analogy with the biology of neurons. The aim of neuromorphic computing and engineering is to recreate the structure of human brain and the functions of neurons to identify the way systems are able to deal with the uncertainty and complexity of the real world. New techniques, such as the Spinking Neural Networks, which incorporate the function of transmitting information by a single neuron just when a threshold value is reached (Wulfram & Werner, 2002), are intended to replicate and mimic brain functions in a more detailed way. This trend has grown over the last few decades as many projects have bene conducted with neuromorphic engineering to computationally simulate a brain; for

[8] On the synthetic method in AI and the need to choose the right constraints for modelling an AI system with an explanatory role see also Lieto (2021).

[9] Both in a virtual and in a synthetic way, that is by computer simulation and building real artifacts respectively, according to a distinction made by Harnad (1994). As previously said, such a distinction is not clear-cut from the point of view of the process of testing and validating a scientific cognitive theory through the synthetic method.

example, the Human Brain Project in Europe. The creation of circuits to bypass the digital software neural simulation (Poon & Zhou, 2011) by means of analog-to-neuron silicon chips is guided by the idea that "the more biological [it] is, the better artificial we get", as biological information-processing is more effective than traditional digital methods,[10] even though the gap with human-cognition level still remains.

Conversely, the biological inspiration of AI is not an easy issue. For example, embodiment issues at the heart of the main notion of bio-inspired AI are debated; it can be argued that it is not clear what "embodied" means. If "embodied" refers to just the sensorimotor approach to cognition, *i.e.* the sensorimotor interaction between an agent and the physical or social world, then it is the grounding cognition to the sensorimotor interaction and is related to a radical cognitive science approach (Chemero, 2009). This approach seems to lack more specific biological characterization, its connections with biological self-regulating mechanisms (Ziemke, 2016), and its organizational nature, which is typical of biological systems from a homeostatic standpoint (Di Paolo, 2003). Not surprisingly, this is a big issue in robotics: how much a body of a robot correspond to a biological body? To what extent is a biological nature of a robot body needed to reach a suitable model of a natural system? And to build an autonomous system?[11] A crucial point concerns the achievable possibilities for the biological inspiration of AI. Damiano and Stano (2018) underline that only the superficial aspects of biological systems and processes are reconstituted in the standard embodied approach, so it is necessary to shift perspective to a different approach that is able to use biological organization in synthetic modeling to reduce the distance between the natural and the artificial. This distance highlights an even more problematic push of AI towards biology and a hard boundary between the natural and the artificial.

The different aspects of the biologization of AI have shown that so far they have given rise to new approaches or attempt as well as to many general theoretical, methodological, and epistemological issues. These issues in part are concerned with the "artificial" of AI. For example, if software or hardware artifacts are similar to a natural entity, then, where does the boundary lie between the artificial model and the natural entity itself? If, what is important are the constraints of an artificial models, and these constraints are relevant insofar as they are what makes an entity a biological one, where is the distinction between the natural and the artificial? To what extent an artificial artifact is no longer artificial and becomes natural in the sense of biological? Presumably, such questions require a better and a newer definition of the artificialness of AI, for theoretical, ethical, methodological, and applied reasons, given that notions usually exploited to answer to them, such as functionalism multiple realizability; biological or non-biological substrates, information processing, and programming vs evolution are currently too narrow and vague to keep on using them as before, when biology and AI, in the AI perspective, were more far-off.

[10] See the conclusion of Mead (1990). On large-scale adaptive analog technology and Very-Large-Scale-Integration (VLSI) digital circuits see also Mahowald, & Douglas (1991).

[11] On robotic modeling in cognitive science see Morse et al. (2011). On the "biological" difficulty to scale the complexity of living beings to build robots at a human-cognition level in situated robotics see the worries by Brooks dating back to 1997: "Perhaps it is the case that all the approaches to building intelligent systems are just completely off-base, and are doomed to fail. […] Perhaps we have all missed *some organizing principle of biological systems*, or some general truth about them. Perhaps there is *a way of looking at biological systems which will illuminate an inherent necessity* in some aspect of the interactions of their parts *that is completely missing from our artificial systems*" (Brooks, 1997: 300–301, *emphasis added*).

4 An Artificial Biology

The idea of a synthetic biology is not an old one. As previously mentioned, synthetic biology is a discipline having within it different aims, methods, and scope that have developed in the last 30 years as outcomes for different technological and scientific achievements. Chronologically, the first important step was the success of the Human Genome Project, which mapped the entire human genome. The possibility of actually mapping every genome for a living being quickly suggested a possibility to build parts of, or an entire genome, for an organism, even for organisms that are not already existent in nature. The road to genome creation moved from virus genomes to bacterial genomes with the aim of building a completely synthetic organism able to autonomously survive.[12] The creation of the base of a living system (DNA) with the same material of a natural, evolutionary-developed system gave rise to a brand-new form of artificiality and to new kinds of machines. These new machines are no longer abiotic. They are "biotic artifacts" (Preston, 2018) that are simultaneously living systems and machines created by human beings.

These kinds of machines are living machines in the sense that can autonomously act and survive in an open-ended environment. In fact, this open-ended environment is the natural environment for all other living natural systems. They are nevertheless built by human beings, which in this case assume the role of designers, even though they are not the controllers, or at least, it is hard to state that the creator in the case of synthetic living systems is in full and complete control of the behavior of the systems themselves.[13] The problem of the distinction between the artificial and the natural in the case of these "machines" aroies again. Where is the boundary between the natural and the artificial? What can we define natural and what artificial as regards these biotic artifacts? There are no easy answers to these questions, at least with the standard use of "artificial" and "natural". This part of synthetic biology makes these kinds of issues awkward. For example, it appears difficult to not define these entities as natural entities if the only difference is not in their material or behavior, but just in the way in which they have been obtained, i.e. is not an evolutionary process, but a laboratory one. This is a big difference, but is it a difference also from the point of view of the natural/artificial dichotomy? Or, on the contrary, it has nothing to do with it?

Nevertheless, this is just the half of the issue concerning synthetic biology. Building parts of biological organisms through BioBricks or the entire genome of an organism, which is put inside a similar organism and starts to reproduce, can give rise to clear-cut questions about the relationship between the natural and the artificial. The other big part of the issue regarding synthetic biology is the one concerning gene manipulation and change, which is better known as genome editing. The most famous editing technology is based on the Clustered Regularly Interspaced Short Palindromic Repeats (CRISPR), a mechanism discovered in bacteria that is used as a defense system against viruses. Roughly speaking, they are sequences of DNA constituting a sort of biochemical memory of the bacterium. The understanding of this mechanism together with the implementation of "associated systems", especially the Cas9 endonuclease enzyme, have allowed for gene manipulation as follows: cutting, inserting, deleting, or substituting DNA sequences through DNA cleavage

[12] Craig Venter, the head of the Research Institute that has created this minimal-genome organism, called it "Mycoplasma Laboratorium" or "Synthia" and the announcement of its creation is quite recent (Service, 2016).

[13] For the issue of prediction in entities of synthetic biology see Bianchini (2018).

of specific and desired targets (Zhang et al., 2014). Cas9 is the enzyme within the cas-gene cluster mediating target DNA cleavage.

This technique shows some problems, such as mosaicism risks or accidental mutations from the introduction of new genes or on the direct modification of a gene. Recent developments have produced similar techniques that are less invasive, because they are editing RNA (Katrekar, 2019). Despite, the fact that this technique is fresh and must be improved over the coming years, RNA editing appears to be more flexible than standard gene therapy. It is based on a family of enzymes called "adenosine deaminases acting on RNA" (ADARs) that are less "invasive" because they are more like an *overwrite* function that changes letters chemically without breaking the RNA molecule's basic structure (Reardon, 2020).

Both these techniques give rise to problems from different points of view. Problems concerning: actual control of outcomes for their application; the consequences on biological systems on which they are used; the (im)possibility to predict the behavior of the organisms that have been edited; and the repercussions generated by an edited organism. These are practical, methodological, ethical, and epistemological problems that will have to be dealt with in coming years. The questions surrounding the natural/artificial distinction are useful to help with tackling these problems and force relevant questions with difficult answers. Are genome-edited organisms natural or artificial? Where does the boundary lie? Does modifying a gene by DNA sequence modification make an organism artificial? Is a less invasive method, if the RNA editing will turn out to be like this with its modifications of a *part* of the process and not of the *source* of the process, more natural and less artificial? And if so, why? On which basis is one allowed to define anything as more artificial or more natural? Most likely, these questions require a re-definition of the notion of artificialness and naturalness because of the epistemological aims related to the foundations of more recent disciplines and for practical, ethical, and normative purposes.

Synthetic biology is not limited to DNA or RNA manipulation or DNA building from scratch and implanting in a natural context—a cell from which the natural DNA has been removed, as in the case of *Synthia* mentioned above. Synthetic biology regards the build of living systems from scratch, too. Research on this topic has been focused on a fully bottom-up approach, which continues to not show achievable or remarkable results. For example, synthetic biology is still far from having synthetic cells that are similar enough to living cells, which does not provide a capacity for autonomous self-sustainment (Stano, 2019). Roughly speaking, it is hard to put together all the pieces that constitute a cell inside a membrane that is used to obtain a dynamic organization typical of living cells.[14] This highlights another potentially hard distinction concerning synthetic biology and is related to the natural/artificial distinction, which is the distinction between living and non-living matter (Deplazes & Huppenbauer, 2009). This is relevant because it shifts the problem to a more complex level that involves the creation of life, a goal that is not achievable by building DNA, but rather requires building a system that can interpret and "use" DNA.[15]

From a wider point of view, synthetic biology is a good candidate to test the potential of a synthetic method for which it is a primary example of its use. In particular, synthetic

[14] Today synthetic cells "are more machine-like (robot-like) than organism-like ("machine" here is intended in its classical meaning, i.e., a device that is built/programmed to perform certain operations decided by the machine builder)" (Stano, 2019: 1–2).

[15] Interesting remarks on this subject are already in Hofstadter (1979), in a chapter about self-reference and self-replication and ending with a paragraph entitled "The Origin of Life".

biology allows for the study, building, and concretizes how-possibly models for biological possibilities (Koskinen, 2017). The possibility to concretize how-possibly models through material entities increases their fruitfulness and allows them to develop in a more concrete, less abstract way that is usually meant in the philosophy of science.[16] The synthetic models reached starting from how-possibly models in synthetic biology are in many cases "constructed on the basis of mathematical/computational models but from biological material, such as genes and proteins" (Knuuttila & Loettgers, 2013: 877); and they improve the use of mathematical/computational models by providing their substantial modification. The combined use of mathematical modeling and synthetic modeling is the core of the synthetic paradigm in synthetic biology (Sprinzak & Elowitz, 2005) and allows for the passage from mere how-possibly models to entities that are relevant by providing more classical, empirical experimental results. What allows for this? The use of the "right kind" of materiality (Knuuttila & Loettgers, 2013). The materiality of the model, that is, of the new biological entity, guarantees that something that is abstractly conceived can become an actual device by developing a biological reality while at the same time a synthetic entity transfers the artificiality of the abstract model to the biological model. Therefore, we arrive in a sort of aporetic situation as follows: (1) either we have to admit that the biological and the natural are not the same, in the sense of superimposable, and are instead quite different; (2) or we must better define what in the biological world is natural and what is not.

These kinds of problems concern the main streams of synthetic biology as follows: (a) the re-design of biological systems, or their parts; and (b) the design and building of new biological systems or their parts. Although the former case shows that artificiality is the recombination of its *natural* parts (for example, DNA or RNA fragments or proteins as BioBricks), which are per se the results of biological evolution, the latter focuses on the use, especially in "chemical synthetic biology", of "*unnatural* molecular parts to do things that are done by natural biology" (*Benner* et al., 2011: 372). Further, artificiality also concerns the parts of the materials of the systems that are not the result of biological evolution. So, (a) is a case of artificial functionality, and (b) is a case of artificial materiality; however, both cases are definable as biological "artificial synthetic systems" (Koskinen, 2017: 499). Where the boundary between artificial and natural lies is, again, hard to say, according to the classic definitions used in the literature.

In more recent discussions about synthetic biology as a field that concretely demonstrates a possibility for multiple realizability, the biological engineering entities are described as *artificial biological systems*, "which share many common features with their naturally occurring cousins but are nevertheless artificial objects with many constrained features", another example that stresses the differences between biological-ness and natural-ness given also that they are "artificial systems which do not have to meet the harsh requirements that natural selection imposes on their fitness" (Koskinen, 2019: 4–7).[17] These systems are the result of a mixture of the natural and unnatural DNA bases. Such engineering and scientific advances are making the boundary between the natural and the artificial blurred.

16 For an example in biology see Forber (2010).

17 For example, artificial biological systems built on the base of expanded artificial genetic alphabets (for one example, see Georgiadis (2015)). See also Warren (2019).

5 A New Definition of the Artificial

So far we have seen how AI and synthetic biology are both growing quickly and are closely related to the notion of the artificial, which pushes them from opposite directions towards the same blurred boundary given their "biological nature". On the one hand, AI, an artificial discipline by definition, has moved towards biology for which it either imitates or is inspired by as a primary target for the building of artifacts that are able to act in an open-ended environment. Conversely, synthetic biology is an "engineered biology" for which the artificial is a matter of manipulation, recombination, or insertion of unnatural material parts of its monocellular or pluricellular systems. They both use the synthetic method to build models and realize them as virtual or real entities. We have seen also that the movement toward biology, actually, is not so simple in AI and synthetic biology. Achieving life and cognition—the two pillars of present-day biology in a broad sense—even at a minimum level turned out to be hard for both these disciplines, being either distant or close to biology, and more than once the enthusiasm of synthetic biology and especially AI scientific and technological research has been disappointed.[18] The recurrent downsizing of AI and synthetic biology desired targets due to a realistic analysis contributes to increase the debate on the artificial as well, as a push to define in the best way such a notion to improve theoretical and applied aspects of research in these two so-far-so-close-to-biology fields.

I will now elaborate in a step-by-step way and develop a new definition of the artificial (known as "Artificial") in relation with the natural to better and further understand AI and synthetic biology in this new way rather than using the classic definitions from the literature. The aim is to achieve a more specific definition for the artificial related to AI and synthetic biology entities for theoretical, experimental, and methodological purposes, which also have by-products in ethical, legal, applied, and political issues that will inevitably be in the coming years on the agenda of various public and private institutions that regulate the research of these fields.

To develop this new definition of "Artificial", I start from the most general and neutral definition of the artificial we may think:

A1: The artificial is what is done by human beings.

It is easy to see that A_1 is too general because there are many human activities that produce something that is not usually not considered as artificial. For example, going for a walk, having a conversation, or having a baby. Therefore, we can refine A_1 as follows:

A_2: The artificial is what is humanly constructed, often using a natural model.

This is a standard dictionary definition and restricts the scope of the artificial to what is formed or created from artistic or ingenious manners by human beings.[19] This is a good definition because it comprises a reference to the natural model and lays aside whether it was developed from imitation or inspiration, but it is far from being effective and useful for AI and synthetic biology, and for two reasons. Although a subfield of AI is devoted to art

[18] The tradition of describing AI as a history of good and bad period is not recent. See for example Crevier (1993).

[19] See, for example, the Merriam-Webster English dictionary: https://www.merriam-webster.com/dictionary/artificial (last retrieval March 14th, 2021).

and creativity (Boden, 2009), the "artistic" part involved by A_2 is not relevant for a specific definition of the artificial in the whole AI (first reason). One could legitimately argue, however, that is not the purpose with which something is contrived, be it artistic, engineering, or pragmatic, the core of the artificial, also for the two disciplines we are dealing with. What matters is *the process* for achieving an artificial thing or entity *more than the target*.

Given this, a second reason seems to be even more remarkable: A_2 is too anthropocentric. This appears counterintuitive, but it is not. Even though it is true that human activity is at the core of a standard, classic definition of the artificial, so that the artificial is defined as what is not natural and does not start from nature, in this sense shows that natural evolution or any other natural process, examples we say above of AI and synthetic biology show the crucial role played by autonomy in artificial systems. Autonomy is necessary to effect in the real world and allows for a system to act, behave, and operate in open-ended contexts while at the same time preserving its dynamic and unceasing environmentally related changes and responses. If this is typical of biological systems, then it is also the same for synthetic biological systems, but it is harder to handle autonomy in AI systems. This issue has been much discussed in literature.[20] Laying aside the many issues of AI autonomy, for the sake of my argument I will assume that autonomy is the ability to operate without the control of a human being. This differentiates a machine such as a mere industrial machinery from an AI non-humanoid robot used for industrial production, or a common car from an AI car. A definition encompassing this aspect is as follows:

> A_3: The artificial is what is humanly constructed, often in a natural model, although it can keep existing and acting/operating/behaving in an open-ended context or environment without human control.

A_3 includes many aspects of AI and synthetic biological systems, especially for the role of human beings to be present at least in the part for the creation or building of the entities/artifacts. An active role for human beings seems to be necessary to categorize something as artificial, although the distinguishing mark of AI and synthetic biological entities is that the human role has to be limited in some sense, *but it cannot disappear*. The causal role of human beings is intrinsically part of the artificial.

A final issue remains that concerns the materiality of particular entities used in this study. A_3 is a suitable definition for the artificiality of AI systems, because it binds autonomy with the human role in building an AI system. A_3 is valid also for every bioinspired AI system, regardless of how similar it could be to a biological (natural or not) entity and is also a constraint that characterizes the heuristics to allow for the creation of robust and flexible AI systems in an open-ended context. Yet, what about materiality? What about artificial systems made up of biological natural or unnatural parts, such as in synthetic biology? A last improvement of the definition is required to create a new form:

> A_4: The artificial is what is humanly constructed, often in a natural model, also through the manipulation of natural systems and processes, and maintains existing and acting/operating/behaving in an open-ended context or environment without human control, regardless the substance or materials of its constituent parts.

[20] For a survey on this topic concerning many AI systems, from algorithms to robots, see Lawless et al. (2017).

A_4 is a good candidate for the definition of "Artificial" because it is enriches in comparison with the standard definition of "artificial". Further, this definition encompasses specific features of AI and synthetic biology, in their asymptotic movement that seems to get closer and closer each other, with the former by moving towards an ever-increasing inspiration from biology (entities, methods, and processes), while the latter by using biological parts in an unnatural way or with unnatural parts in a biological genetic context.

Many issues are not solved by A_4, and this corroborates further the evolution of the notion of the "artificial", which will be presumably more complex in consequence of the advances of AI and synthetic biology. For example, are AI systems created by AI systems built by human beings still Artificial? The answer is yes if the causal role of human beings is still valid also indirectly or if it is mediated in some way. In other words, if the causal chain of events can be traced back to entities that were not the ones assessed from an Artificial point of view. And what about cyborgs? Are they Artificial since they have one or many non-biological parts embedded in their biological body? No matter how many particular cases there are, A_4 should help with the assessment of what is the Artificial for AI and synthetic biology. Also, in subfields like A-life, for which it is not odd to assert that "the methods and insights of ALife have been also permeating into biology, in the sense that computational modeling is now commonplace in all branches of biology. Will the successes of ALife imply its absorption into the mainstream study of life? […] If this tendency continues, soon A Life will no longer be 'artificial'" (Aguilar et al., 2014: 10). My hypothesis is that other research areas and scientific fields will be soon no longer be seen as "artificial", at least in the classical sense of the term.

6 Conclusions

In this article, I have argued that the common distinction between the natural and the artificial is no longer useful because of the birth and development of new sciences, i.e. AI and synthetic biology. AI and synthetic biology are mainly characterized by a synthetic method in their building models as much as the realizations of them as artifacts or, more generally, as "artificial entities". Their construction marks them as artificial. Even though it is true that the synthetic method in AI has been used, especially in first periods of its development, to carry on the program of "psychological" AI, which is closely related to cognitive science and the study of mental life (Cordeschi, 2002), synthetic method has broadened its scope to many AI sub-fields and with different aims that are mostly apparent in robotics. In other disciplines such as synthetic biology, the synthetic method has been used to build artificial biological entities that show there could be something artificial in the biological that can further change its fundamental nature together with a way to consider it not only from an engineering perspective, but also from a theoretical, experimental, and ethical perspective. The growing shift of AI towards biology through inspiration heuristics is the other side of this bringing the artificial into the biological, which also changes the natural.

I have proposed to refine the standard definition of "artificial" to reach a new more specific definition that is able to categorize new aspects of the artificial, which have originated from the development of AI and synthetic biology to build future scientific research in new directions and with new machines.

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