Chapter 17
The Dynamic Universal Creativity Process

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Abstract In this chapter we introduce the Dynamic Universal Creativity Process (DUCP), defined as the active ensemble of all creativity episodes in the evolution of our cosmos. It is shown how this construct descends naturally through a shift in the leading perspective in creativity studies: from a focus on static creative achievements to the consideration of dynamic processes, which even transcend their agents. Four mechanisms for the dynamic extension in time and space of creativity episodes are presented: continued exploration, concatenation, estimation, and exaptation. The concepts of wide-sense and strict-sense creativity are introduced to allow the consideration of four layers of existence in the DUCP: material, biological, psycho-social, and artificial. The theoretical and practical implications of these definitions are discussed, also in view of contributing to the mending of the cultural fracture between science and the arts, under the flag of creativity studies. A description of the creativity mechanisms characterizing the material, biological, psycho-social, and artificial layers is provided, highlighting intra- and inter-layer concatenation potential and achievements. Among other concepts, complex systems, biological evolution, bipedalism, neoteny, individual and social mind-based behaviour, as well as artificial intelligence, all find an integrated place in the framework of creativity studies, under the DUCP umbrella. Implications on educational systems of the future are drafted in the final discussion.

17.1 Introduction

We live in a world of constant change, and there is a widespread feeling in society that the pace of this change is constantly increasing (Corazza et al. 2010; Feather 2013; Rosa 2003). Taking on an anthropocentric view, the human species should collectively be considered the prime actor in this accelerating evolution, which is

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first and foremost cultural and economic, but it is also heavily affecting the environment, in both its geo-physical and biological dimensions. Considering the psychology of individuals and the sociology of their relationships, this enormous power for change can arguably be attributed to the creativity and anticipation powers of the human mind (Corazza 2017a), not at all in isolation but deeply intertwined with the fundamental human predispositions and abilities for communicating, learning, and for social life in general (Glăveanu 2011). Indeed, researchers in cultural evolution have recognized that creativity is necessary to explain the exponential growth of cumulative culture (Enquist et al. 2008). Even though creativity has always existed in our species, the current evolution in society calls for new interdisciplinary approaches and efforts to transform creativity studies into a self-standing scientific discipline, with important bearing upon human well-being, and with impact on developmental and educational matters (Corazza 2017b). This chapter should be considered a contribution in that direction, focusing more on ultimate than on proximal questions (Alessi 1992).

Our discussion begins by considering the definition for creativity. While the debate on the selection of requirements for creativity is still open (e.g., see Martin and Wilson 2017, and references therein), the so-called standard definition for creativity foresees that this phenomenon requires both originality and effectiveness (Runco and Jaeger 2012). In other words, for an entity to contribute to the growth of cumulative culture it must be original, i.e. novel, authentic and non-obvious, as well as effective in introducing new forms of (possibly domain-specific) value, such as utility or aesthetics. However, as discussed in (Corazza 2016), the possession of the attributes of originality and effectiveness actually define a creative *achievement*, i.e. the conditions for which the outcome of a creative process succeeds in being recognized as creative, at least by a group of people in a certain environment (Stein 1953). But creativity is a journey, and creative efforts are not always met with success: on the contrary, challenging the state-of-the-art, exploring new avenues, trying to solve ill-defined problems, engaging in new artistic compositions, or in general trying to contribute to the growth of cumulative culture invariably opens up the space for failed trials, frustration, and difficult interactions with an inside dialogue and an outside world which are quick to judge and reject. Recognizing that this blue side of the creativity medal is not only real but actually very important in the process, especially in the pursuit of developing creativity in educational settings (Beghetto 2010), a *dynamic definition for creativity* has been proposed (Corazza 2016): creativity requires a *potential* for originality and effectiveness. A single word carries the difference that makes the difference: *potential*. The higher the potential (which depends on task at hand, personal characteristics of all those involved in the creative act, goals, motivation, environmental characteristics, resources and blocks, etcetera), the higher the level of creative activity and the chance to arrive at one or more creative achievements, which are however never guaranteed *a priori*. In this framework, when out of the creative process a successful product emerges, the potential is realized and an instance of *creative achievement* occurs. On the contrary, when there is no outcome, or the outcome is rejected by internal or external assessment, it is possible to recognize an instance of creative *inconclusiveness*, from which very important lessons can be learned; and given that sufficient motivation and resources are still available, the process is not concluded but pushed forward in the pursuit of the original or modified objectives. Previous investment should not be wasted (Sternberg and Lubart 1991), and in fact it is well known that the history of artistic and scientific genius was paved by persistence (Albert 1983; Edison 1948; Eysenck 1995; Galton 1869; Simonton 1984).

It is important to underline how the introduction of potential *inside* the definition of creativity has the power to transform the framework from an analysis of static attributes (originality and effectiveness) to the description of a dynamic process characterized by the possible prospective to deliver items with the desired attributes. This, which is in line with dynamic approaches to cognition (Beer 2000), constitutes a very clear and distinct shift in emphasis from product to process, using the classic terminology of Rohdesian tradition (Rhodes 1961), and it leads us to pursue the understanding of the profound, pervasive, and never-ending nature of the creativity process: this is the aim of the present work. In pursuing this goal, we will encounter the definition of creativity episodes and their mechanisms for extension in both time and space, the concepts of concatenation potential and evolutionary tree of creativity, to culminate in the discussion of the dynamic universal creativity process and its layers: material, biological, psycho-social, and artificial. While creativity in the strict-sense only pertains to the psycho-social layer, we will discuss the theoretical and practical reasons why it is useful to integrate also other layers in a universal wide-sense view of creativity. From a metaphysical perspective, our intention is to advance on the path traced by Alfred North Whitehead in his cosmology (1978/1929), addressing the ontological question by establishing that *creativity existed since the origin of our universe, and potentially permeates all of our universe.* We believe that the consideration of wide-sense creativity alongside with strict-sense creativity helps reducing the dramatic divarication between science and the arts, which has plagued our culture for centuries.

We start by observing the difficulty, which turns out to be an impossibility, to delimit the creative process with fixed boundaries.

17.2 Creativity Process: A Never Ending Story

Assuming a local, or microscopic, perspective, the creativity process can be shown to contain a minimum of three elements (Corazza and Agnoli 2015): (a) gathering and structuring of input elements (goal and relevant information); (b) generation of outcomes (ideation); (c) estimation and verification of the effects (assessment and implementation). Many additions and variations would be possible around this core, but this is not the point here. What matters is that it would seem possible to delimit the start and the end of the process quite precisely, both in time and in space, as well as in the involved actors. But taking on a global perspective, a macroscopic approach that considers all possible instances of creativity, it becomes apparent, perhaps surprisingly, that the creativity process cannot have a clean slate start nor a unique end, anywhere at anytime. The observation of a time-limited instance remains a very useful simplification, but it always amounts to a form of reduction. And this interconnectivity between creative instances may in fact be one of the *strongest reasons for advocating a dynamic approach in creativity studies*. Four mechanisms are identified below that lead to the extended development of the creativity process in the time and space domains.

First, and most obvious, is the case of *continued exploration*, which can be pursued in case the creative agent (or agents) is not yet satisfied by the achieved outcomes (even though outside observers would think that the results are already of great value, as was evident for example in the correspondence between Vincent Van Gogh and his brother Theo; Van Gogh 1978) or, more often, in case of creative inconclusiveness (Corazza 2016): no result of value has been obtained yet, exploration should continue, other solutions should be tried out, content improvement or better aesthetic representation would be necessary, and so on. Upon reflection, it is clear that in principle there is no intrinsic and fixed boundary to delimit the amount of resources that can be invested in continued exploration during a creative task.

Second, it is very interesting to realize that, even in the presence of significant, satisfying, and presently acclaimed creative achievements, the creativity process will still continue, in a very natural sense: in fact, the process always includes the *estimation* of the impact of its represented outcomes; but the evaluation of the originality and effectiveness of an outcome is bound to dynamically change over time and space (Corazza 2016; Glăveanu 2014), depending on what can be defined as the cultural state of those who are confronted and interact with the product itself. Given the fact that the process contains the impact over time of its products, both within and outside the domain of relevance, it follows that the creative process can go on well beyond the production of its outcomes: every creative instance has the potential to generate long waves of cultural interaction.

Third, as a consequence of cultural communication, the outcome of a creative task might become an ingredient of yet another creative activity, carried out by the same or different agent. In a metaphoric sense, creative products can be thought of as stairs in a ladder: each one is important but only as an element of the whole, without which the function and the overall purpose would be lost. And for any achievement of today, we can identify the fundamental elements introduced by previous generations that are the essential enablers for this progress. In the accumulation of culture, serial and parallel *concatenation* links can be identified between different local instances of the creativity process. These concatenations are not accidental but necessary, so much so that it is impossible to truly understand the creativity of today without considering the creativity of yesterday, and therefore of the day before, and so on indefinitely.

Fourth, and perhaps most surprising, it is important to realize that the potential for originality and effectiveness of an outcome is not limited nor restricted by the intentions or goals that characterized the process that generated the product itself. In the ensuing dynamics, *the very same product might acquire a totally new function*, clearly distinct from the original goals, and thus become a completely different creative achievement, which in some cases can even be seminal in giving life to a new branch of knowledge. This phenomenon may be identified as *exaptation*, following a terminology introduced by Gould and Vrba (1982) in evolutionary biology, to indicate those features that in the present enhance the fitness of an organism, but that were not historically selected by nature for their current role. The classic example is that of feathers, which evolved in certain variations of dinosaurs (e.g. the Archaeopteryx) for thermal regulation, and later on exapted for flight by birds (Gould and Vrba 1982). The phenomenon of exaptation has been shown to be more a norm than an exception not only in biology but also in many technological fields (Andriani and Cattani 2016; Garud et al. 2016). A paradigmatic case is given by the business evolution of Corning, which in the seventies of the twentieth century exapted the technology previously used for glass production to develop optical fibers, turning its consolidated, standard venture into a cutting-edge, high-technology firm (Cattani 2005, 2006). Exaptation points to the fact that it is effectively impossible for anyone to foresee all the possible future implications of an innovative idea. For this very reason, we introduced the term *estimation* in place of judgment or assessment of creative ideas in (Corazza 2016): estimation is an open-ended and dynamic step in the creativity process.

Table 17.1 recaps these four fundamental mechanisms identified for the dynamic extension of the development of a creativity instance.

From this discussion, agreement should follow on the fact that the dynamic process representing the creativity phenomenon from a macroscopic perspective cannot really be considered to be definitely concluded at any fixed time instant: it can certainly be locally interrupted because it was just an educational exercise or a test, or because of exhaustion of resources or motivation in the case of creative inconclusiveness, or because of reaching sufficient satisfaction in the case of a creative achievement; but the interruption is never an intrinsic property of the process. Surprisingly, this is independent from the fact that the outcomes of a creative process

Table 17.1 Mechanisms for the extended development of a creativity process instance

Mechanism for extension	Description
Continued exploration	All creativity processes involve the possibility for different outcomes, with unprestatable multiplicity and variable degrees of originality and effectiveness. Exploration of this space of possibilities can continue indefinitely, in spite of failures or successes occurred during the search.
Estimation of creative outcomes	The outcomes of a creativity process must be evaluated for their originality and effectiveness: there can be no final judgment by anyone, but only an estimation that depends on time, space and culture. Estimation extends dynamically throughout the cultural lifetime of the outcome.
Concatenation	Any outcome of a creative process has predecessors and successors, containing inherently both traces of past creative instances and the possibility to become an ingredient of a subsequent or parallel creativity instance, as part of a concatenation of creativity episodes.
Exaptation	The outcome of a creative process may subsequently acquire new functionalities and purposes, possibly completely different from those that drove the originating process.

are generated and exist (and that they are possibly exploited for their utility): the process can be carried on irrespectively. On the other hand, for the practical purposes of description, it is useful to enucleate an instance whereby an agent or agents define a goal, enact a creativity process instance, produce outcomes, and possibly enjoy a creative achievement as judged by themselves, or by fellow peers, or by experts and judges. Let's identify this instance as a *creativity episode*. In this view, when models and frameworks for the creativity process have been proposed (e.g., Corazza and Agnoli 2015; Kaufman and Baer 2004; Mumford et al. 1991; Sternberg 2006; Wallas 1926), it can be stated that they fulfilled the goal of describing with variable levels of detail the development of *a single creativity episode*, i.e. from a microscopic perspective. On the other hand, due to the fundamental dynamicity of the phenomenon, these episodes are never effectively concluded nor disjoint, as discussed above. In Fig. 17.1 a graphical representation of a creativity episode with its relevant mechanisms for dynamic extension is drawn.

The input to the creativity episode is represented in general as a concatenation to previous knowledge, excluding creation ex-nihilo. Previous knowledge is of course consolidated in culture and exchanged through social learning, but we underline here that its origin can in any case be ascribed to some past creativity episode, to which current creativity episodes are conceptually concatenated. Continued exploration forms essentially an iterative loop on the episode, which can persist irrespective of the fact that either achievement or inconclusiveness occur; bidirectional dynamic interaction with the environment (including concatenation with parallel creativity episodes) is always present to influence the development of the episode under observation; three further mechanisms are then envisaged as extensions in the time and space dimensions of a creativity episode: (a) estimation of the value and originality of the episode's outcomes, which can lead to dynamic appreciation/criticism across time and cultures; (b) concatenation of this episode into future creativity episodes (either through its outcomes, its methodologies, or simply by information exchange); (c) exaptation of the outcomes for new and unpredictable purposes, with no appreciable change to the ideas/products themselves. Clearly, as

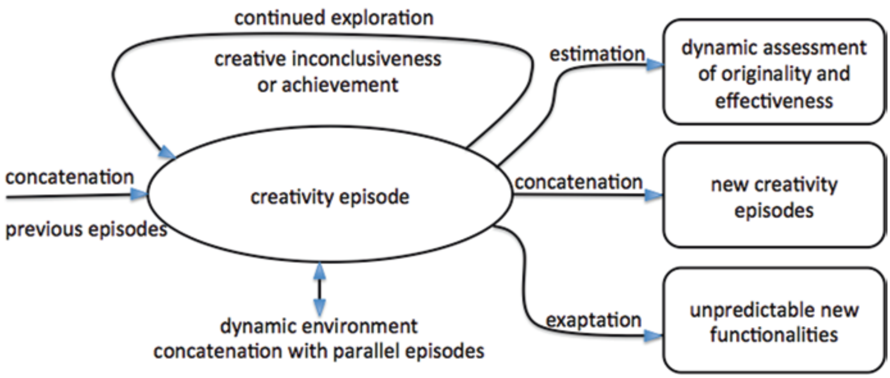

Fig. 17.1 A creativity episode and its possible extension mechanisms

it was argued that the subdivision into creativity episodes can be somewhat arbitrary, it follows that the boundary between two interconnected episodes can most often be debatable: it is in fact a matter of modelling. Perhaps, an identifiable discontinuity can be related to a change in the agents involved in the episode; but even this case can have exceptions, for example considering diverse teams collaborating on research and innovation focused on the same technology.

A crucial point should be made here: *none of the foreseen extension mechanisms should be interpreted as producing cause-effect relationships with creative achievement*. In fact, if there were a direct cause-effect relationship between a mechanism and the subsequent outcomes, the originality element of the products would irremediably be lost. Therefore, the extension mechanisms only provide a *potential* for future achievements, but no certainty. In particular, the availability of past creativity episodes provides a *concatenation potential* for further achievements, which is reminiscent of the *adjacent possible* concept by Stuart Kauffman (2016); but this concatenation potential cannot be ascribed of causing those achievements. Originality emerges out of the ingredients provided by the concatenation with extant cultural elements, but it cannot be reduced to them. If it could, the process would entail induction or deduction, but not creativity.

Let's focus now onto the main consequence of this section: accepting the proposition that the creativity process does not have an intrinsic end, irrespective of the fact that the agents involved can and do change over time and space, all creativity episodes can conceptually be concatenated and concur to form an overall process. *The creativity process appears to transcend its actors*, or in other words *all actors are contributing to one collective process*. This realization leads us to pose a number of ultimate questions: What is the nature of this unified creativity process? Can it be identified as a universal entity? Can its origin be traced? What is its role in our cosmos?

17.3 The Dynamic Universal Creativity Process

While a great number of scientific articles address the definition of a creativity episode (see for example Corazza 2016; Martin and Wilson 2017; Mayer 1999; Parkhurst 1999; Runco and Jaeger 2012; Simonton 2012; Weisberg 2015), this is likely to be the first proposal for a definition of the *dynamic universal creativity process* (DUCP), as follows:

> *The active ensemble of all creativity episodes in the course of cosmic evolution.*

Several comments are in order to justify the choice of the terms used in this attempt for a DUCP definition. First, the ensemble of all creativity episodes should be intended as a tree-shaped set that grows throughout history, containing items that are linked together either directly (through adjacent concatenation, exaptation, estimation) or indirectly (through common ancestors and remote interaction). In other words, this DUCP definition implies that even considering creativity episodes with goals and outcomes that appear to be completely unrelated, by going back in time it should always be possible to find a common ancestor. In this sense, the ensemble of all episodes can be thought of as an "*evolutionary tree of creativity*." We will return on the ontological problem of the origin, or root, of this tree, and its cosmologic implications. But why is this ensemble "active"? Essentially, this is due to the fact that it is virtually impossible to take a permanent picture of this ensemble, in the sense that any two pictures taken at different times will always be significantly different, not only for the new additions, but also observing the past. This fundamental attribute of the evolutionary tree of creativity is due to the process dynamics, through its mechanisms of continued exploration, concatenation, estimation, and exaptation: as an example, once the outcomes of an episode are linked to a new creativity episode, the estimation of the former is also actively modified, by acquiring new values, new interpretations, and new impact. In other words, a present time creativity episode will actively lead to modifications in a past creativity episode. The same applies to parallel (contemporaneous) episodes: knowing that other agents are working creatively in a specific area actively modifies the process under consideration. This requires that inter-episode communication takes place at some stage, or that posthumous interconnection is created by those analyzing the relevant subject. The active ensemble of all creativity episodes is therefore a live tree, dynamically interconnecting past, present, as well as future elements of the universal creativity process, and producing the exponentially growing accumulation of culture.

But why is there a need in the DUCP definition to extend the tree span to the entire course of cosmic evolution, well beyond the boundaries of human and animal evolution? This is a very delicate step, which requires careful consideration. As many philosophers would argue, creativity appears to require intention, understanding, communication and judgment, and as such only a species capable of those constructs could be the agent of proper episodes of this phenomenon. For example, on this page we find the work of Berys Gaut (2010), who states (p. 1040): "Creativity is a property of agents, not of mere things or plants. [...] The kinds of action that are creative are ones that exhibit at least a relevant purpose (in not being purely accidental), some degree of understanding (not using merely mechanical search procedures), a degree of judgment [...] and an evaluative ability directed to the task at hand." While we agree with Gaut that this position describes creativity in a strict sense, we still want to be open to other wider sense forms, if they turn out to be useful in pragmatist terms. Possibly, the widest appreciation of the creativity phenomenon is the one proposed by Alfred North Whitehead, who in his famous work "Process and Reality" (1978/1929), delineates a cosmologic theory in which creativity is the ultimate metaphysical principle (p. 21): "Creativity is the universal of universals, characterizing ultimate matter of fact. It is the ultimate principle by which the many, which are the universe disjunctively, become the one actual occasion, which is the universe conjunctively. It lies in the nature of things that the many enter into complex unity." Clearly, in Whitehead's view there is no need for explicit intentionality, as creativity is intrinsic in nature, instantiated moment by moment and thus forming ("creating") actuality. In this wide-sense perspective, all episodes that have a potential to generate elements showing attributes of originality and effectiveness in our universe qualify as proper elements of the DUCP. By accepting this wide-sense view on creativity, the need to consider the entire evolution of our cosmos in the definition of DUCP descends directly. This entails the acceptance of a much greater variety of episodes inside the creativity realm. But before we proceed, let's ask ourselves if is this truly useful, from both theoretical and practical perspectives.

Considering first the theoretical perspective of creativity studies, the benefit in taking a wide-sense view on creativity should be searched in its resonance with existing movements towards the unification of all disciplines of knowledge. In this direction, it is possible to refer to the work of Gregg Henriques regarding the so-called Tree of Knowledge (ToK) and the theoretical unification of the field of psychology (Henriques 2003, 2011), whereby an integrated epistemological view is presented as based on four layers: matter (the domain of physical sciences), life (the domain of biology), mind (the domain of psychology), and culture (the domain of social sciences). Each layer is characterized by growing levels of complexity. Interestingly, Henriques points out that each layer is fundamentally based on the layers underneath, yet it cannot be reduced to them. For example, in moving from matter to life, Henriques notes (2003, p. 158): "Although genes are coordinated populations of molecules, individual molecules are not "small" genes. Genes are irreducible points of complexity […]." In doing so, the notion of consilience introduced by Edward O. Wilson (1998) is acknowledged but also apparently surpassed, in the sense that there seems to be no possibility to unify all knowledge under a definite number of natural laws: this is prevented by the irreducibility of disciplines from higher layers into lower layers. Another epistemologically unifying point of view is that presented by Chaisson (2009), based on the ubiquity of change and the transversal concept of energy to give rise to all forms of complexity in our universe, along a non-reversible progress of time. Let's note that in (Chaisson 2009) the "creativity" keyword is apparently missing: from a theoretical point of view, we argue that there is a necessity to open a discussion about *the role of creativity in cosmic evolution*. We start an attempt to address it here; clearly, given the ambition of such a task, it will not be possible to come to a complete framework or definite conclusions: initial considerations will have to suffice. Further, there is yet another theoretical reason behind this extension of DUCP to multiple layers of existence, brought in by taking proper account of dynamic and circular interrelationships: originality in one layer of existence can actually be the reason for creativity in another layer, which in turn might create an iterative feedback loop. For example, technological creativity of humans may affect the environment (e.g., temperature increase), which spurs biological variations (e.g., selected species hyper-flourishing through adaptation or exaptation) as well as geo-thermic and atmospheric reactions (e.g., ozone-layer depletion), which in turn require and spur more technological innovations (hopefully in more sustainable directions), as we are seeing today. Taking a macroscopic perspective, these inter-layer DUCP loops do become visible, thus allowing a holistic view on reality from the perspective of creativity studies.

On the other hand, from a practical point of view, to justify our DUCP definition we resort to pragmatism as also elected in (Corazza 2016), drawing upon the pragmatist maxim by Peirce (1992–1999, p. 132): "Consider what effects, which might conceivably have practical bearings, we conceive the object of our conception to have. Then, our conception of those effects is the whole of our conception of the object." Therefore, considering a wide-sense creativity construct that extends the DUCP reach to the entire realm of cosmic evolution (as opposed to confining it only to human and possibly animal evolution) can be usefully conceived only based on its practical bearings, i.e. its utility in terms of the development of creativity studies and in particular of the understanding of the creativity construct for the purpose of contributing to the establishment of a scientific discipline (Corazza 2017b; Corazza and Agnoli 2015). Therefore, our task should be to show that extending the consideration of creativity also to other layers of complexity, beyond those of life, mind, and culture, does provide unifying and useful perspectives that have practical bearings onto creativity studies for humans. We believe that this is indeed the case; we will provide a few examples later in this chapter, but this will also constitute a goal for future work.

The above discussion, which of course would also merit to be expanded but is deemed to be sufficient for our present purposes, contains all the essential elements of our theoretical and practical justifications to define DUCP as the active ensemble of creativity episodes in the course of cosmic evolution. In doing so, and in line with Whitehead's philosophical perspective, we can address the ontological question by establishing that *creativity existed since the origin of our universe and potentially permeates all of our universe*, in all its layers of existence.

In other words, we argue that creativity has been and is the engine for extended evolution in all layers of existence reported in Table 17.2, which are reminiscent of the ToK classification (Henriques 2003) but are actually only partially the same. In particular, both the "mind" and "culture" ToK layers are included here in the Psycho-Social layer, given the difficulty or even the impossibility of separating individual from social aspects in creativity; secondly, we introduce an additional layer of complexity due to the rise of artificial intelligence, the effect of which can be seen today but will become ever more evident in the next decades. As indicated in Table 17.2, the first two layers share the fact that the creative process occurs without apparent forms of "intelligence": agency is intrinsic in nature, following Whitehead's cosmology. On the other hand, the third layer is characterized by intelligent and purposeful forms of creativity, which is in line with the position held by Gaut, still without contradicting Whitehead. Regarding the fourth layer, the pertinent

Table 17.2 DUCP forms in the four layers of existence

Layer of existence	DUCP form	Creativity sense	Creativity form
Material layer	Material creativity process	Wide-sense	Emergent and energy-driven
Biological layer	Biological creativity process	Wide-sense	Emergent and aptive
Psycho-social layer	Psycho-social creativity process	Strict-sense	Intelligent and goal-driven
Artificial layer	Artificial creativity process	Wide-sense	Artificially intelligent

philosophical discussion is but in its infancy: can one really admit a form of creativity produced by machines?

Our next step is to consider these four layers of existence in turn, to describe the specific DUCP characteristics and extract those principles that may prove to be useful for a discipline of creativity, in pragmatist terms.

17.4 The Material Creativity Layer in the DUCP

Adding the adjective *material* to *creativity*, thus implying the generation of novelty with the exclusion of any form of life-based agency, is certainly a remarkable conceptual challenge. Our intention is to include in this domain all those phenomena taking place in the physical world that have a potential to generate originality and effectiveness, without the necessity of the action of any living form that could be ascribed the causing, estimating, or even perceiving of the corresponding outcomes. By observing our universe, at least the small portion that is available to our present-day exploration, it is immediate to realize that the vast majority of the cosmic environments are indeed purely material and inanimate. For what we know so far, life appears to be a beautiful exception reserved to the Earth. Even accepting the idea that there *must* be life somewhere else in our universe, it would be difficult to hypothesize that life is a widespread phenomenology. Therefore, the ontological issue about the *material creativity* construct can be translated into the following questions: Does creativity exist in our universe at large? Or is it a very special exception, related to special forms of life? Can the physical, material world generate original products which are also effective? Who or what can estimate this originality and effectiveness, and does this matter? The issue is first and foremost philosophical and, as we discussed above, it would see on opposite fronts thinkers such as Gaut (critical) and Whitehead (favourable). To progress in our discussion, it is important to note that of all possible entities that the human mind has been able to approach scientifically, the material world is the one that is most amenable to be described with mathematical laws, mainly pertaining to the realms of physics and chemistry. Therefore, for us to admit that creativity can exist in the material world, it must be that the laws of physics and chemistry, at least in specific conditions, allow the existence of "solutions" that are unpredictable, surprising, novel, i.e., in a word, original, but also effective, in terms of having an impact on the evolution of our cosmos. The laws of classical mechanics do not appear to have these characteristics: they are deterministic, and given that the initial conditions are known with a sufficient accuracy, the future evolution of the system under consideration can be predicted with any wanted precision. No surprises and therefore no creativity is allowed by those equations. Even the laws of statistical and quantum mechanics, although they describe phenomena which are probabilistic in nature, still produce solutions that are predictable, albeit only in a statistical sense. Very problematic appears also to be the fact that the second theorem of thermodynamics dictates that "in a closed system at equilibrium, entropy can never decrease". Given that entropy can be largely interpreted as the opposite of order, and therefore of effectiveness in a cosmologic sense, it would appear that this mathematical framework leaves no room for material creativity in our world. However, how could the universe have developed and continue to expand, starting from a big bang and henceforth giving birth to particles, galaxies, stars and planets, if creativity did not have a place in the material world? Could anyone deny surprise, beauty, and astounding complexity to the universe in which we exist? And how could the conditions to support life in general, and the human mind in particular, have been generated on Earth and not anywhere else, without a surprising process of creativity happening at the material layer? These would seem to be hardly solvable dilemmas from a scientific point of view, unless a new theoretical framework is invoked. In passing, we should note that, starting from the seventeenth century, this apparent incompatibility between the laws of classical physics and creativity contributed to divaricate a dichotomy between science and the arts, between positivism and romanticism, from which our culture has been and is still suffering dreadfully. It would be extremely important to re-integrate our culture into a unity, and this is one of the main practical reasons why it is important to accept a wide-sense view in creativity studies, along with the standard strict-sense perspective.

Luckily, in the last five decades a solution path to the above dilemmas has emerged: the thermodynamics of irreversible processes (Prigogine 1967), or the study of physical systems that are far from equilibrium, which are dissipative in nature and therefore require an exchange of energy to exist: these systems can behave in ways that have a potential to be a-priori unpredictable, original, but also effective; in our terminology, they can be creative in the wide sense. Ilya Prigogine, the Nobel prize for chemistry in 1977, played a key role in establishing this new approach to the study of the inanimate world, which contributed fundamentally to the science of complex and chaotic systems, and in particular to the phenomenon of emergence of surprising behaviour out of physical matter, leading to the end of the "certainty" provided by the previous physical-mathematical frameworks (Prigogine 1996). In what sense, then, can material originality be generated? Imagine a physical system existing in conditions of strong energy exchange with the surrounding world to keep it away from a static equilibrium, and that it is desired to predict the evolution in time of the physical behaviour of that system, given certain starting conditions. Now, Prigogine and others have proved that, under specific assumptions, even infinitely close but different starting conditions can give rise to solutions that diverge exponentially with time (Prigogine 1996). This ensuing uncertainty can also produce new forms of order that *emerge* from the system's behaviour, but that cannot be reduced to a cause-effect relation according to any physical law. When an unpredictable behaviour that demonstrates superior effectiveness in terms of order and sustainability emerges out of a physical system, we state that a *material creative achievement* has occurred. We should note the fundamental role played by *energy* in creating the potential conditions for emergence: only with a sufficient energy supply is it possible to create those far from equilibrium conditions that are conducive to material creativity. In other words, material creativity is related one-to-one with the availability and expenditure of amounts of energy which are much larger than those that would be needed to keep a system in equilibrium. And the Big Bang is our scientific explanation of the largest and seminal energy surge in the history of our universe, giving rise to all of its material richness.

Let's observe that the study of physical complex systems and the phenomenon of emergence has been taken as a useful metaphoric and explanatory framework for human creativity by a number of authors (e.g., Ambrose 2014; Gabora 2017; Loreto et al. 2016). Under this light, the construct of material creativity that is proposed here should be easily acceptable. At the same time, we underline that here we go beyond the metaphor: this may be the first instance in which material creativity and human creativity are seen as different elements of a unique, universal creativity process: the DUCP.

We close this chapter by a sort of quantification of the production of material wide-sense creativity in the course of the evolution of our cosmos. The current estimate for the extant number of galaxies could be a reasonable measure in this case: Conselice et al. (2016) calculate that there should be in the order of two trillion galaxies in our universe, each with billions of stars, each with the possibility to have planetary systems around them. This astonishing richness constitutes the first layer of DUCP production. And these systems of planets produced by material creativity open up new worlds of concatenation potential, where original outcomes might imply the opportunity to go beyond the material layer itself: this is certainly the case for our planet Earth.

17.5 The Biological Creativity Layer in the DUCP

Current estimates date the formation of the Earth at around 4.5–4.6 billion years ago (Wetherill 1990; Allegre et al. 1995). The formation of a new planet is a clear evidence for the growth of order in the universe, which we classify as an impressive material creative achievement, given its originality and time-lasting effectiveness. Clearly, conditions for life were not yet in place on Earth at the end of the accretion of its materials: our planet was still blind of any biological possibility, but it had a sort of mysterious potential for it. The insurgence of life on Earth, which from a disciplinary viewpoint could be interpreted as the emergence of biology from chemistry and physics, is the first, most surprising, extraordinary creative achievement to be accounted for in the biological layer of the DUCP. Could any other wide-sense or strict-sense creative achievement compete with the instantiation of *life* in a completely inanimate and therefore hostile environment, in terms of its beautiful originality and breathtaking effectiveness? We believe the answer is no. It is very important to underline that even though life emerged in an inanimate material world, life cannot be reduced to the material world with any form of cause-effect relationships. Biology builds on chemistry and physics, but it cannot be reduced to them (Henriques 2003). Life forms a completely distinct layer of creative activity in the DUCP, the biological creativity process driven by *aptation*, which includes both adaptation (Darwin 1859) and exaptation mechanisms (Gould and Vrba 1982). The general outcome of the biological DUCP layer can in general be identified as *biodiversity*.

There are many theories and beliefs regarding the insurgence and development of life on Earth, and this chapter is clearly not the place for a review of such an intricate, sensitive, and amply debated matter. For our purposes, it will suffice to refer to the recent work by Olivia Judson (2017) on the relationship between the various sources of available energy and the evolution of life on Earth. As a matter of fact, it appears that the history of the evolution of life and biodiversity on Earth can be partitioned into five epochs, based on the prevailing energy source utilized by living organisms. On the one hand, two of these sources were provided directly by the material layer: geochemical energy, produced by reactions of water with basalt and other rocks, and sunlight produced by our star at the center of the solar system. On the other hand, three of the sources were original and effective consequences of the biological DUCP process itself: oxygen, flesh, and fire. This is a powerful evidence for the concatenation potential between creativity episodes, both intra- and inter-layer. Let's briefly review the overall process, following Judson (2017). During energy epoch one, phylogenetic and biochemical evidence shows that the earliest organisms were chemoautotrophs exploiting geochemical energy to perform simple chemical reactions (their primitive form of "life"). These proto-organisms could survive only near geochemical sources, so that distribution of life was scattered and erratic on the Earth surface. Energy epoch two started when, around 3.7 billion years ago, an original behaviour emerged: some bacteria evolved to harness sunlight to accelerate and drive their chemical reactions. At first, these reactions were anoxygenic (did not produce oxygen), and oxygen remained at trace levels on Earth. A crucial innovation happened when one phylum, the cyanobacteria, developed oxygenic photosynthesis: in the course of about 300 million years, this would produce the Great Oxidation event, completely transforming the atmosphere of the Earth. It is important to note here that this great biological creative achievement had an impact on the material layer, transforming the physical environment and allowing completely new opportunities for concatenation potential. Oxygen was provided by the DUCP biological layer and not by the material layer, but it completely transformed the latter along with the former. We classify this phenomenon as inter-layer concatenation. Given its availability, the exploitation of oxygen as an energy source constitutes epoch three, starting around 2.4 billion years ago: the ozone layer was established, minerals were largely diversified, new areas of the Earth were colonized by those organisms that evolved to become able to exploit the concatenation potential offered by oxygen, in particular the possibility to construct original and effective molecules such as collagen. It is during this epoch that eukaryotes emerged, that would eventually produce vegetation: flora was born, and the Earth became green. One innovation by the eukaryotes is particularly of relevance: phagocytosis, or the engulfment of particles and other life forms. This led to the start of a completely new epoch, one in which energy for an organism could be derived by eating other organisms: energy epoch four, whereby flesh was an additional and phenomenal source of energy. Around 575 million years ago, animals became abundant and energy could be acquired through hunting, rapidly transforming the Earth ecosystem:

before this epoch, most of the life forms were microbial, but by eating flesh organism sizes grew rapidly and enormously, opening up the possibility for an exponential growth in biodiversity. Fire is the last innovative source of energy to be considered to conclude this overview. Throughout the solar system, only on Earth the three requirements for the existence of fire are satisfied: lightning for ignition, oxygen for combustion, and wood for fuel. The necessary concatenation of material and biological creativity episodes should be evident: without oxygen and/or without vegetation, fire would not be possible. Somewhat surprisingly, fire turned out to be a powerful promoter of biodiversity: it drove the initial growth of flowering plants, which in turn led to diversification in fauna species such as ants, bees, and mammals; fire also produced concatenations back to the material layer through the introduction of original and effective materials such as charcoal, ash, and soot. But, undoubtedly, the most crucial concatenation potential afforded by fire was the evolution of a fire creature: *Homo*. Indeed, hominids learned to control the use of fire, using it for protection, metal molding, and especially for cooking. The ability to cook changed completely the energy acquisition of hominids, because cooked food, be it meat or vegetable, is essentially pre-digested and thus delivers more energy for the same quantity. Diet diversification and thus the ability to live in many places on Earth were original and effective consequences carrying astonishing concatenation potential for hominids.

Also in the case of the biological layer of the DUCP, it would be interesting to give a quantitative measure of the overall wide-sense creative production. Perhaps, a useful number could be the total number of extant species on Earth, which is actually a subject of active debate (Caley et al. 2014). At any rate, most of the available figures circle around five million species, of which we have named about 1.5 millions (Costello et al. 2013). Indeed, the complexity produced by biodiversity goes beyond our imagination.

Finally, let's note that, similarly to the theory of complex systems, also biological evolution and biodiversity have been taken as inspiration for the modelling and explanation of the creative thinking process, starting with Campbell (1960), and later followed by Simonton (2012). This is certainly a powerful metaphor, and its use is legitimate even though subject to debate. What we must underline here is that, in the theoretical architecture of DUCP, biological evolution is not simply a useful metaphorical framework but an integral part of the wide-sense creativity process, concatenated in hardly extricable ways to the strict-sense creativity of the psycho-social layer.

17.6 The Psycho-Social Creativity Layer in the DUCP

Amongst the creative achievements of the biological layer in the DUCP, the advent of species harnessed with a brain should receive major recognition. Indeed, the overall exercise of biological evolution could be interpreted as an immense and longitudinal problem-solving exercise, aimed at expanding life, colonizing all of the

Earth, surviving as individuals, avoiding species extinction, and all of this in spite of an ever-changing physical environment, plagued by earthquakes, volcano explosions, atmospheric fluctuations, as well as glaciations. The necessary adaptations and exaptations for survival required major investments in terms of both individual sacrifices and/or time, in many cases occurring in the course of millions of years. Now, a drastic reduction in this required investment was afforded by the introduction of the immense flexibility of the brain, allowing a multitude of alternative behaviours in front of the same conditions, which can be tried and assessed even by a single individual in the course of its own lifetime. A much faster and effective modality for adaptation and exaptation. In addition, although social behaviour does not necessarily require an encephalon, it is a fact that species endowed with brains show much higher levels of mutual interrelationships and an ability to exploit these in order to improve their own sustainability. Overall, this leads to the emergence of another DUCP layer, the psycho-social layer, in which *Homo Sapiens* is without a single doubt the most prominent actor, and where individual minds collaborate for a variety of goals, increasing DUCP productivity and complexity by orders of magnitude. Given that material and biological layers are already part of the DUCP, it should be taken for granted that variable levels of potential for originality and effectiveness are a feature of all animal species (for a review, see Kaufman and Kaufman 2004); but, for the sake of brevity, we shall focus here only on hominids, and *Homo Sapiens* in particular. Given the intentionality and conscience afforded in particular by the human mind, the DUCP psycho-social layer constitutes what we consider to be the creativity process *in the strict sense*. However, when we try to identify the conditions that were conducive to the emergence of strict-sense creative behaviour in hominids, it is interesting to note that once again concatenations with significant events in the DUCP material and biological layers become evident.

The history of the human side of the DUCP psycho-social layer necessarily starts in Africa. As noted by Van Couvering et al. (2004), no other continent can rival with Africa in terms of its importance for human evolution. Briefly, around ten million years ago the displacement of the Western and Eastern African tectonic plates produced an original and effective reconfiguration of the environment: the Great Rift Valley was created, a depression of approximately 6000 km in length from North to South. The Great Rift Valley formed an obstacle to Atlantic atmospheric perturbations, so much so that the Eastern territories of the African continent became more and more arid. This produced a drastic reduction of the rainforest in vast areas, and opened up the concatenated potential for a new ecosystem: the savanna. Until then, hominids could easily live out of fruits and roots picked up in the forest. But without the forest, new sources of food were necessary. The new environment thus opened a new opportunity which was also a great challenge: how to hunt prey, without exposing oneself to excessive risk? Hominids were certainly neither the fastest nor the strongest of animals. It was in these conditions that an idea with a great potential for originality and effectiveness was generated: bipedalism. Bipedalism carried with itself numerous advantages: seeing far (particularly useful in the savanna), the possibility to wade waters, a great variety of diversified movements, and most of all the freeing of hands. On the other hand, just like any other disruptive idea, bipedalism implied also a series of negative sides: it required anatomical reorganization and with that new difficulties in giving birth, vital organs were more exposed, joints wore out more rapidly, and it was a difficult skill to learn for babies. Nonetheless, this innovation was gradually adopted to become a major biological and psycho-social creative achievement in spite of all the underlying obstacles. This was truly a crucial step forward, as underlined from a biomechanical point of view by Vaughan (2003) and from a philosophical perspective by Gallagher, considering its implications in terms of embodied cognition (Gallagher 2015, p. 99): "If humans had not attained the upright posture […], the human brain would likely be much smaller, our sensory and motor systems would be different (more attuned to the olfactory than to vision), and none of it would function in the specific way it functions now. Indeed, we would likely have to redefine what we mean by rationality". And, we add, we would have to redefine what we mean by creativity.

A second crucial step in the development of strict-sense psycho-social creativity in humans should be underlined: neoteny, or the persistence of immature behaviour for long periods of life, up to adulthood (Bjorklund 1997). Also in this case, the are both advantages and disadvantages to take into account. On the negative side, neoteny implies much longer care periods for our babies than any other animal species, with children who are not capable of searching or hunting safely, which forced a reorganization of social roles between males and females. On the other hand, this feature brought positive sides of exceptional importance from the point of view of enhancing creativity, i.e. the potential for original and effective behaviour: long time available for playing and a strong mother-child relationship, whereby the development and refinement of language and metacognition took place, with grand implications for the future of our species.

Hominids thus became the major force inside the psycho-social layer of the DUCP: they began to shape their environment and to produce inventions, starting from stone-tools, and they affected at the same time the material and biological layers. To date, the earliest account for the inception of the stone-tool industry appears to be given by the archaeological findings in Lomekwi 3, West Turkana, Kenya (Harmand et al. 2015): they are dated at 3.3 million years ago. Building stone tools is characteristic of a psycho-social creative activity in that the potential effectiveness is projected into the future, implying the existence and use of mind. Now, 3.3 million years ago is about three million years earlier than the advent of *Homo Sapiens*, and almost one million years before *Homo Abilis*, who was also identified as one of the initiators of human creative activity (Gabora and Kaufman 2010). We want to highlight again that this finding is in line with Whitehead's hypothesis that the agent in the DUCP is the universe as a whole, so that in the psycho-social layer all hominid species can and should be accredited of creative behaviour at various degrees. However, no one could argue against the fact that DUCP productivity exploded in the hands of *Homo Sapiens*, thanks to our unprecedented ability for learning and communication, thus enhancing enormously the potential for concatenation, exploration, exaptation, and estimation. *Homo Sapiens'* cumulative culture has been shown to be growing exponentially across all times (Lehman 1947), and this exponential growth has been attributed to our creativity (Enquist et al. 2008), as noted before. Even though it is patently self-referential, we cannot avoid being astonished at the cumulative culture that *Homo Sapiens* has been able to produce in the course of its evolution.

Let's conclude this section by noting that our view of the psycho-social layer of the DUCP is in accord with the approach to economics by Koppl et al. (2015), whereby they theorize that economic dynamics are "creative", in the sense that the relevant phase space changes continually in ways that cannot be prestated. Reminiscent of biodiversity, they introduce the concept of *cambiodiversity*, or diversity in traded goods, with an estimated dimension of ten billion goods for sale in New York city in 2015. This, along the findings by Lehman (1947) on the exponential growth of cumulative culture in all disciplines across history, can be taken as forms of quantification of psycho-social productivity of the DUCP.

17.7 The Artificial Creativity Layer in the DUCP

The action of *Homo Sapiens* in the psycho-social layer of the DUCP has produced vast numbers of inventions based on scientific discoveries, opening up new professions and disciplines, among which those pertaining to information and communication technologies (ICT). Cybernetics, or the science of communication and control theory, was born in the middle of the twentieth century, when computing machines were in their pre-history, foreseeing a progression path which turned out to be very close to reality: today, modern supercomputers are reaching computational powers that are comparable to those of the biological human brain. Given the rate of increase in computational power and density, we can expect that machines might surpass the human brain in terms of raw computational power, while they already outperform us for specific tasks, such as for example arithmetic calculus or chess playing. At the same time, telecommunication infrastructures have interconnected the developed world, upon which the Internet and the World Wide Web have introduced services that have soon become pervasive and in some cases even necessary to our everyday and professional lives. Artificial intelligence has been developed to a sufficient level to enter into our everyday life, most of the times without being noticed. The Internet, with its powerful search engines, constitutes nothing less than the most powerful form of non-anthropomorphic distributed artificial intelligence, of which the majority of the world's population makes daily use. Our minds are now extended by these technologies (Menary 2010), and the job market is undergoing radical transformations (Brynjolfsson and McAfee 2014). The question for us is: should we include any of the outcomes of artificially intelligent processes as part of the DUCP? Is there a philosophical as well as practical possibility for machines to behave creatively? Since originality contains an element of authenticity, shouldn't creativity be an impossibility from the computational point of view? These are crucial questions which will require much more space than what we can dedicate here. Let's only say that the field of computational creativity is today open (see for example Colton et al. 2009, and the references therein), and that as a minimum we should consider the fact that machines can provide useful tools to enhance psycho-social creativity. Indeed, as discussed in (Corazza 2017b), we believe that the collaboration between humans and machines will be a fundamental characteristic of the future Post-Information Society.

17.8 Conclusions and Further Developments

This chapter represents but a quick initial flight over the vast territory to be covered in order to transform Whitehead's cosmological interpretation of creativity as the ultimate universal metaphysical principle into a fully-fledged theoretical framework, with practical consequences in a pragmatist sense. The first fundamental step into this process is the realization that once a dynamic definition for creativity is given in terms of potential originality and effectiveness, it becomes virtually impossible to fragment the creativity process into separate elements: creativity episodes can be carried on indefinitely, transcending their actors, and they are all interrelated. The consequence of this realization is the definition of the Dynamic Universal Creativity Process (DUCP) as the active ensemble of all creativity episodes in the course of cosmic evolution, to form an evolutionary tree of creativity. This definition allows to place into a single theoretical framework the original and effective outcomes of the material layer (mainly the domain of physics and inorganic chemistry), the biological layer (mainly the domain of biology and organic chemistry), the psycho-social layer (mainly the domain of psychology, social sciences, and economics) and the artificial layer (mainly the domain of engineering, computer science, and cybernetics). The successive layers build on, but can never be reduced to, one another, due to the intrinsic and emerging characteristics of each layer. It can be shown however that DUCP outcomes at one layer can spur iterations of innovations at other layers, with recursive mutual influences. This kind of circularity is one justification for an integrated approach to creativity: other justifications have been provided in terms of both theoretical and practical benefits. Clearly, a large amount of work will be needed to consolidate this theoretical framework and deliver practical implications, involving multiple disciplines among which psychology, philosophy, anthropology, cosmology, evolutionary biology, economics, design, engineering and cybernetics will have prominent roles.

One question which remains to be answered is the following: which implications can be derived from the adoption of the DUCP framework in terms of education, and in particular of education for creativity? Answering this fundamental question will require extensive future work, but we can start drafting preliminary answers here. Indeed, the impact appears to be far from negligible. First of all, the dynamic definition for creativity allows to take into account in a unified framework not only the desired creative achievements, but also episodes of creative inconclusiveness, which put to a test the resilience and self-efficacy of students. Therefore, the fundamental attitudes and mindsets for persistence can be recognized and developed under this dynamic perspective. Second, from an epistemological point of view, adopting DUCP implies that teachers and students should be formed and informed about a search for the possible unification of knowledge, going beyond barriers and dichotomies that are typically the result of historical disciplinary subdivisions as sorts of fenced gardens. We are specifically concerned with bridging the gap between science and technology on one side, human sciences and art on the other. Third, recognizing that creativity has a universal and metaphysical character should convince teachers and students that this is not a topic that can be excluded from any educational strategy; rather, it should find its proper collocation, one that can well exploit the material, biological, psycho-social, and artificial transversality of the DUCP, letting those willing to be involved in the DUCP become part of an endless flux of creativity episodes. Fourth, and perhaps most important, given that creativity will be essential to the survival of the human species in the post-information society, the development and measurement of skills and abilities related to creative performance, the understanding of the socio-cultural implications of creative activity, as well as the search for the overall conditions that can optimize the potential for originality and effectiveness in any circumstances should be addressed and become a positive element in the design of future education systems. We add a sense of urgency to these guidelines, given the accelerating pace of societal transformations (Corazza 2017b).

The attentive reader will have noticed that, throughout this discussion, we have avoided completely the question of whether the advancements produced by the DUCP at the various layer could or could not be supervised or guided in any teleological form. This was done on purpose to let each reader find her/his own position on this fundamental metaphysical question, which also touches upon the sphere of personal spirituality. Indeed, an intimate place which we intend to respect.

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