Exaptative Thinking as What Makes Us Human

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1 Introduction

The term *exaptation* was coined by Gould and Vrba (1982) to denote what Darwin referred to as *preadaptation*: the exploitation, or cooption, of an existing trait to carry out a new and different purpose. The exapted trait must be both necessary and sufficient to carry out the new purpose. A good example of biological exaptation is feathers. Although feathers originally evolved to provide insulation and improve temperature regulation, they were later co-opted to facilitate flight (Gould and Vrba 1982). Exaptation involves what has been referred to as the adjacent possible (Beckage et al. 2011), or the realm of *near potentiality* (Gabora and Aerts 2009), because it involves the modification of existing structure or dynamics in a way that is neither *presently actual*, nor *impossible* (Fig. 1).

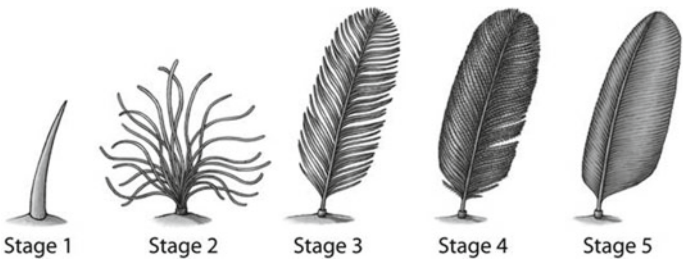

Fig. 1 The biological exaptation of a feather, from developing filaments for insulation, to eventually facilitate flight Adapted from "Novelty and innovation through exaptation" by Silvia Rita Sedita, 2018

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Biological exaptation occurs when selective pressure causes potentiality to be exploited. Like other kinds of evolutionary change, exaptation is observed across all levels of biological organization, i.e., at the level of genes, tissue, organs, limbs, and behavior. Exaptation is also present in the cognitive processes that underlie cultural (Gabora et al. 2013), cognitive (Gabora and Carbert 2015), and economic (Dew et al. 2004) change. Indeed, to explain the concept, Gould and Lewontin (1979) originally used the notion of a spandrel. The term *spandrel* refers to the roughly triangular space between the tops of two adjacent arches and the ceiling. Such spaces were originally nothing more than a by-product, until artists realized they could paint designs in these areas, thereby enhancing the aesthetic quality of the building. Such designs soon became the preeminent aspect of these spaces, much as swim bladders, which originally evolved to facilitate vertical movement in the water column, eventually turned into lungs, and thereby acquired what is (for, us at least) its most important function of enabling survival on land. Thus, a spandrel is a cultural artifact as opposed to a biological trait (Fig. 2).

Exaptation in the cultural and economic domains is the result of a certain form of cognition, which can be referred to as exaptive thinking, or *psychological exaptation:* the capacity to adapt a particular pattern of thought or behavior from its original application to a new one, or the re-purposing of an object designed for one use for use in another context (Gabora et al. 2013). Psychological exaptation is related to what Rothenberg (1971, 2015) calls Janusian thinking, which involves achieving a new outcome by looking at something from a different perspective.

As an example of psychological exaptation, consider the invention of the tire swing. It came into existence when someone re-conceived of a tire as an object that could form the part of a swing that one sits on. Much as the current structural and material properties of an organ or appendage constrain possible re-uses of it, the

Fig. 2 The arch on the top depicts a plain spandrel, which was later used as a space to create aesthetically appealing designs (the arch at the bottom); an example of cultural exaptation

current structural and material properties of a cultural artifact (or language, or art form, etc.) constrain possible re-uses of it. Incongruity humor constitutes another form of psychological exaptation; an ambiguous word, phrase, or situation, that was initially interpreted one way is revealed to have a second, incongruous interpretation. Exaptation of representations and ideas dramatically enhance the ability to not just cope with the technological and social spheres of life, but develop individualized perspectives and unique worldviews conducive to fulfilling complementary social roles (Gabora and Smith 2018). This increase in cognitive variation provides the raw material for better adaptive fit to selective pressures.

Waste recycling is a particularly interesting example of exaptation in the cultural domain because of its applications to sustainability efforts. In waste recycling, an item that is a wasteful by-product in one context is found to be useful in a different context. Yet another example is data transformation, in which data in one format is changed to a different format while preserving the content so that it can be put to a different purpose or made easier to interpret or understand (as in the visualization of astronomical data).

This chapter proposes that while biological exaptation results in novelties that have adaptive value for a perpetuation of the kind of self-sustaining structure to which we refer to as "alive," psychological exaptation results in novelties that have adaptive value for a second kind of complex, self-perpetuating structure, a *worldview,* i.e., an integrated network of understandings that collectively provide a way of *seeing* the world and *being in* the world (Gabora 1999, 2012). We will look at how this form of psychological exaptation differs from both the kind that animals engage in, and from biological exaptation, and how it makes possible a second kind of evolutionary process: the evolution of culture.

2 Psychological Versus Biological Exaptation

Although biological and psychological exaptation are similar in their outcome, the underlying mechanisms are different. In biological evolution through natural selection, exaptation occurs through a *breadth-first process* involving the random generation of numerous variants and selective retention of the fittest. Millions of possibilities may be tried in parallel, the vast majority of which are either neutral or deleterious, but the occasional one is beneficial, and thus more likely to be inherited by the next generation. In other words, natural selection relies on the capacity to try out multiple possibilities simultaneously and select the fittest. Psychological exaptation, in contrast, is more *depth-first;* as few as a single possibility is brought to mind and progressively modified until the goal state is achieved.

This depth-first process is not random but strategic and capitalizes on the architecture of associative memory to make educated guesses about how previously acquired knowledge could be put to new uses. More specifically, memory is distributed (i.e., encoded items are spread out across multiple neurons) and content-addressable (i.e., there is a systematic relationship between the content of an item, and the location of the neurons involved in its encoding). This cognitive architecture enables knowledge and ideas that are relevant to the task at hand to come to mind naturally without systematic search (Gabora 2017).

3 Exaptive Thinking in Humans Versus Other Species

It is said that many species can be *creative,* i.e., they can come up with new ways of foraging or escaping predation, and some even use tools. According to the animal behavior literature, the innovation process consists of four stages in: *sampling, exploring, problem solving,* and *learning*, the last of which includes incorporating the solution into a behavioral repertoire (Sol 2015). These four stages bear some resemblance to Wallas' (1926) four stages of the creative process: preparation, incubation, illumination, and verification. The notion of "sampling" appears to be related to the notion of "problem finding" (Getzels and Csikszentmihalyi 1976; Mumford et al. 1994; Runco and Chand 1994), and the first two of Sol's stages map onto the "generate" and "explore" stages of creative cognition (Ward 1995). Moreover, the trait referred to in the animal behavior literature as *neophilia* (Sol 2015) appears to be close in meaning to the human personality trait of "open to experience;" both entail risk-taking, going new places, and trying new things.

These similarities might suggest that psychological exaptation in humans differs from that of other species only in degree, not in kind. However, while animals are capable of problem-solving—e.g., opening a lid to find hidden food—they are incapable of art-making and scientific theorizing. Their exaptive thought processes appear to be the result of trial and error, as opposed to strategy and intuition. We can refer to exaptation through trial and error as *generic exaptation:* it comes about through chance processes and just happens to be beneficial. It is proposed that both biological exaptation and the psychological exaptation of animals, is of this form.

When innovations are essential for survival, the nexus of traits underlying innovative capacity become canalized. A phenotypic response to an environmental condition, such as a learned innovative behavior, can over time be *genetically assimilated*, and thus innate. Some limitations of innate behavior are (1) it is rather inflexible, and (2) it operates over the course of biological generations. Thus, while some kinds of innovation may be genetically assimilated, it is unlikely that the innovations that fuel human cultural evolution are, given that they can unfold spontaneously over timeframes of hours or minutes (e.g., humorous internet banter).

This leads to another significant difference between human innovation and that of other species. Their innovations do not *evolve;* i.e., it is only humans whose innovations exhibit change that is adaptive (enhances the survival, well-being, or reproductive capacity of its bearers), open-ended (i.e., the space of possibilities is not limited), and cumulative (i.e., one modification builds on another in such a way as to improve utility or bring aesthetic pleasure). There may be random variations in the way the action is implemented from one individual to the other due to copying error, differences in size, or shape, or the presence of injuries, resulting in individual differences in how a particular idea is implemented behaviorally. However, such accidental differences do not form the basis of a process of cumulative change such that cultural outcomes become increasingly useful, specialized, psychologically therapeutic, and artistically expressive.

The inability of other species' innovations to evolve is not due to their incapacity to spread innovations from one individual to another. Many species can imitate, i.e., copy what their neighbors are doing, and thereby benefit from an action without inventing it from scratch; however, their imitation does not result in a process of adaptive, open-ended, cumulative change as is observed among humans.

We said above that what differentiates psychological creativity from biological creativity is that it is depth-first, and that this was made possible by a cognitive architecture that was distributed and content-addressable. Other species' cognitive architecture is, like that of humans, distributed and content-addressable, and as in humans, this endows them with a higher than chance probability of stumbling upon relevant, workable solutions. However, they encode situations in less detail, which makes their mental representations less distributed than those of humans; in other words, fewer neurons participate in the encoding of any particular experience. Thus, for example, say you had been tasked with the task of an informal chair that conformed to the sitter's shape. If your mental representation of the experience of throwing a beanbag omitted the detail that the beanbag conformed to the shape of your hand, then any neurons that are tuned to respond to experiences involving "conform to shape" would not be activated. These neurons would therefore not make the connection between a beanbag experience and the need to make a chair that conforms to shape, and therefore you would not be able to invent the beanbag chair. The human brain encodes experiences in sufficient detail that neurons that were activated in one context are re-activated in other contexts, allowing associations to forge more readily between experiences that are connected in different ways, and enabling unusual ideas to come to mind.

Generic exaptation can be contrasted with *strategic exaptation,* in which knowledge, past experience, and/or intuition are involved in the transformation of an old idea into a new one, to the point where it may be difficult to detect traces of the original source of inspiration in the innovation that eventually resulted. It is proposed that this is what differentiates psychological exaptation in humans.

Because an innovator's repertoire of knowledge and experience is continuously updated, psychological exaptation is not just strategic; it is flexible and dynamically responsive to current needs, trends, or tastes, and can improve over time as new knowledge and experience are obtained. Humans exhibit individual differences in the extent to which they dynamically modulate their innovations in response to changing environmental conditions. Such differences can also be found at the organizational level, and perhaps the cultural level as well.

The upshot is that although other species can engage in psychological exaptation, it is our capacity for a particular kind of exaptive thought that differentiates us: the capacity for recursive exaptive thought, such that the output of one exaptive thought is the input to the next, and to do so drawing upon the collective contents of one's worldview, until a perceived need is met, a question has been answered, or an inviting aesthetic possibility has been explored. This process has been called *representational redescription* because the contents of working memory are recursively redescribed, or restructured by drawing upon similar or related ideas (Karmiloff-Smith 1992). The process may involve looking at something from different real and imagined perspectives, at different levels of granularity (from fine details to big picture), and different kinds of thought processes, bits, and pieces fall into place (Gabora 2010, 2017, 2019; Sowden et al. 2015). This, in turn, has enabled us (for better or worse) to collectively transform the planet we live on.

4 Exaptation in the Service of Self-sustaining Organization

Human exaptation is not just strategic and dynamic; it is carried out in the service of a structure that is self-organization and self-mending. Such a structure is very different from that of a database. Like some neural networks, this structure is hierarchical and modular, and capable of learning through local interactions among its parts. However, unlike a neural network, it uses emotions as signposts in the effort to *preserve* a higher-level pattern of global interconnectedness. More formally, human psychological exaptation arises in virtue of the goal of maintaining an organizational structure that is Reflexive, Autocatalysis, and F-generated, sometimes referred to as a RAF (Gabora and Steel 2017; Hordijk et al. 2011; Hordijk and Steel 2004, 2016; Steel et al. 2019). The term *reflexive* is used here in its mathematical sense, meaning that every element is related to the whole. In a biological context, the term *food set* refers to the reactants that are initially present, as opposed to those that are the products of catalytic reactions. In a psychological context, the term food set refers to knowledge and experience that comes from direct sensory experience in the world, including socially transmitted information; thus, non-foodset items consist of thoughts and ideas that are the result of reflection, imagination, or creative thinking. In its biological context, the term autocatalysis refers to a set of catalytic molecules in which each molecule is either part of the foodset or can be generated through a sequence of reactions starting from the foodset, such that as a whole they can be reconstituted. A human mind is *autocatalysis* when it contains a network of memories and/or knowledge items that are (similar to the biological situation) inter-accessible by way of sequences of mental operations such as reminding events. Be they biological or cognitive in nature, structures that are reflexive, autocatalysis, and foodset-generated (sometimes called *f-generated*) are referred to as RAFS.

The RAF framework has been used to model the transition toward the kind of cognitive organization capable of evolving culture (Gabora and Steel 2017, under review). This model followed up on the proposal that the increased complexity of Homo erectus culture compared with other species such as Homo habilis reflected the onset of the capacity for representational redescription (Corballis 2011; Donald 1991; Gabora and Smith 2018; Hauser et al. 2002; Penn et al. 2008). Representational redescription would have enabled the forging of associations between mental representations, thereby constituting a key step toward autocatalysis structure. Representational redescription enabled the emergence of hierarchically structured concepts, making it possible to shift between levels of abstraction as needed to carry out tasks composed of multiple subgoals. A computational model of cultural evolution that showed that the mean fitness of ideas across a society of artificial agents increases with the introduction of two innovation enhancing abilities: (1) *chaining*, the ability to combine simple ideas into complex ones, and (2) *contextual focus*, the ability to shift from a convergent to a divergent processing mode when the fitness of one's current actions is low (Gabora and Saberi 2011; Gabora and DiPaola 2012). Moreover, both factors—chaining and contextual focus—proved most useful in times of environmental fluctuation (Gabora et al. 2013). Of course, care must be taken in extrapolating from a simple computational model to the real world. However, the computer experiments are not the only source of support; Chrusch and Gabora (2014) synthesized these computational modeling results with findings from behavioral genetics, psychology, and anthropology to produce an integrated multi-level account of how chaining, contextual focus, and thereby human creative abilities could have evolved.

5 Exaptation in the Clinical Context

The human worldview has been shown to be self-organization, self-healing, and autopoietic (Gabora and Merrifield 2012). Psychopathology, or mental illness, is characterized by significant distress in an individual, in a variety of contexts (American Psychiatric Association 2013). There is a sense of fragmentation, disorientation, or disordered processing of one's experiences. It can be conceptualized as difficulty engaging in the aforementioned processes to organize one's worldview. Psychological exaptation then, can be seen as a skill that can be developed in individuals to help organize their worldviews, to accommodate distressing events and experiences such that they become productive, and more meaningful to them. In other words, an exaptive thought process can enable a negative life event to be recontextualized, such that it is framed in a manner that aids in psychological well-being. Indeed, several psychotherapeutic approaches, such as cognitive reframing in CBT (Beck 2011), and trauma processing in EMDR (Shapiro 1997), although they do not explicitly frame it as such, involve psychological exaptation.

6 A Quantum Framework for Exaptation

A mathematical framework for exaptation has been developed (Gabora et al. 2013), which could in fact be said to be a quantum model, not in the sense of Penrose, but in the sense that it uses a generalization of the quantum formalism that was developed to model situations involving extreme contextuality in the macroworld. The state of a trait (or the starting point for an idea) is written as a linear superposition of a set of basis states, or possible forms the trait (or idea) could evolve into, in a complex Hilbert space. (For example, the basis states might represent possible ways of using a tire). These basis states are represented by mutually orthogonal unit vectors, each weighted by an amplitude term. The choice of possible forms (basis states) depends on the context-specific goal or adaptive function of interest, which plays the role of an observable. (For example, in the context of wanting to create a playground someone turned a useless tire into a tire swing). Observables are represented by self-adjoint operators on the Hilbert space. The possible forms (basis states) corresponding to this adaptive function (observable) are called eigenstates. In this model, innovative capacity did not evolve as an exaptation from some other, selected-for adaptive trait. Rather, innovation itself—or at least the retooling of an object or idea by considering it from a new point of view—is modeled as exaptation.

Examples from both biological evolution and the evolution of cultural novelty through innovation have been worked out using the quantum model of exaptation. The approach has also been used to model cross-domain creativity, i.e., the restructuring of an idea by considering it from the perspective of another discipline or incorporating an inspirational source from another subject area (Gabora and Carbert 2015).

7 Summary and Conclusions

This chapter summarized ongoing research comparing and contrasting biological and psychological exaptation. Psychological exaptation—the capacity to adapt a particular pattern of thought or behavior from its original application or context to a new one—differs from biological exaptation in arising out of structural change at the neural level as opposed to the genetic level, and in being strategic, as opposed to a matter of trial and error.

It is likely that at least some of the behavioral innovations of animals qualify as psychological exaptation. However, their innovations do not build cumulatively on one another, and thus do not evolve. Psychological exaptation plays a key role in creativity, though they are not quite the same thing. Creativity often involves reiterated change to a concept or idea by looking at it from different perspectives until there is an internal sense of completion, and the external creative output feels finished. Creativity contributes to the evolution of a second kind of self-organization, essentially “autocatalysis” structure: an integrated, self-sustaining internal model of the world, or worldview.

Both biological and psychological exaptation have been mathematically modeled using a generalization of the quantum formalism, which is specifically suited to modeling change under the influence of a context.

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References

American Psychiatric Association (2013) Diagnostic and statistical manual of mental disorders, 5th edn. American Psychiatric Association, Arlington, VA

Beck J (2011) Cognitive behavior therapy: basics and beyond. The Guilford Press, New York, NY

Beckage B, Gross LJ, Kauffman S (2011) The limits to prediction in ecological systems. Ecosphere 2(11):1–12

Corballis MC (2011) The recursive mind. Princeton University Press, Princeton, NJ

Chrusch C, Gabora L (2014) A tentative role for FOXP2 in the evolution of dual processing modes and generative abilities. In: Bello P, Guarini M, McShane M, Scassellati B (eds) Proceedings of the 36th annual meeting of the cognitive science society. Austin TX: Cognitive Science Society. (Held July 23–26, Quebec City), pp 499–504

Dew N, Sarasvathy S, Ventakaraman S (2004) The economic implications of exaptation. J Evolut Econ 14:69–84

Donald M (1991) Origins of the modern mind: three stages in the evolution of culture and cognition. Harvard University Press, Cambridge, MA

Gabora L (1999) Weaving, bending, patching, mending the fabric of reality: a cognitive science perspective on worldview inconsistency. Found Sci 3(2):395–428

Gabora L (2010) Revenge of the 'neurds': characterizing creative thought in terms of the structure and dynamics of human memory. Creat Res J 22(1):1–13

Gabora L (2012) Dynamical disequilibrium, self-transformation, and the evolution of a sustainable worldview. Chaos Complex Lett 6(1–2):37–44

Gabora L (2015). A communal exchange-based framework for cultural evolution. In R. Dale, C. Jennings, P. Maglio, T. Matlock, D. Noelle, A. Warlaumont & J. Yashimi (Eds.), Proceedings of the 37th annual meeting of the Cognitive Science Society. Austin TX: Cognitive Science Society. (Held July 22–25, Pasadena), pp 2835–2836

Gabora L (2017) Honing theory: a complex systems framework for creativity. Nonlinear Dyn Psychol Life Sci 21(1):35–88

Gabora L (2019) Reframing convergent and divergent thought for the 21st century. In: Goel A, Seifert C, Freska C (eds) Proceedings of the 2019 annual meeting of the cognitive science society. Cognitive Science Society, Austin TX, pp 1794–1800

Gabora L, Aerts D (2009) A model of the emergence and evolution of integrated worldviews. J Math Psychol, 53: 434–451

Gabora L, Carbert N (2015) Cross-domain influences on creative innovation: preliminary investigations. In: Proceedings of the 37th annual meeting of the cognitive science society, pp 758–763

Gabora L, DiPaola S (2012) How did humans become so creative? In: Proceedings of the international conference on computational creativity. Palo Alto: association for the advancement of artificial intelligence. ISBN: 978-1-905254668. (Held May 31–June 1, Dublin, Ireland), pp 203–210

Gabora L, Merrifield M (2012) Dynamical disequilibrium, transformation, and the evolution and development of sustainable worldviews. In: Orsucci F, Sala N (eds) Complexity science, living systems, and reflexing interfaces: new models and perspectives. IGI Global, Hershey, PA, pp 69–77

Gabora L, Saberi M (2011) An agent-based model of the cognitive mechanisms underlying the origins of creative cultural evolution. In: Goel A, Harrell F, Magerko B, Prophet J (eds) Proceedings of the 8th ACM conference on cognition & creativity. New York: ACM Press. (Held Nov 3–6, Atlanta, GA), pp 299–306

Gabora L, Scott E, Kauffman S (2013) A quantum model of exaptation: incorporating potentiality into biological theory. Prog Biophys Mol Biol 113(1):108–116. [http://arxiv.org/abs/1310.0558]

Gabora L, Smith C (2018) Two cognitive transitions underlying the capacity for cultural evolution. J Anthropol Sci 96:27–52

Gabora L, Steel M (2017) Autocatalytic networks in cognition and the origin of culture. J Theor Biol 431:87–95
Getzels JW, Csikszentmihalyi M (1976) The creative vision: a longitudinal study of problem finding in art. Wiley, New York
Gould SJ, Lewontin R (1979) The spandrels of San Marco and the panglossian paradigm: a critique of the adaptationist programme. Proc R Soc Lond B 205(1161):581–598
Gould SJ, Vrba ES (1982) Exaptation–a missing term in the science of form. Paleobiology 8:4–15. https://doi.org/10.1017/S0094837300004310
Hauser MD, Chomsky N, Fitch WT (2002) The faculty of language: what is it, who has it and how did it evolve? Science 298:1569–1579
Hordijk W, Kauffman SA, Steel M (2011) Required levels of catalysis for emergence of autocatalytic sets in models of chemical reaction systems. Int J Mol Sci 12(5):3085–3101
Hordijk W, Steel M (2004) Detecting autocatalytic, self-sustaining sets in chemical reaction systems. J Theor Biol 227(4):451–461
Hordijk W, Steel M (2016) Chasing the tail: the emergence of autocatalytic networks. Biosystems 152:1–10
Karmiloff-Smith, A. (1992). Learning, development, and conceptual change. Beyond modularity: A developmental perspective on cognitive science. The MIT Press.
Mumford MD, Reiter-Palmon R, Redmond MR (1994) Problem construction and cognition: applying problem representation in ill-defined domains. In: Runco MA (ed) Problem finding, problem solving, and creativity. Ablex Publishing Corporation, Norwood, NJ
Penn DC, Holyoak KJ, Povinelli DJ (2008) Darwin's mistake: explaining the discontinuity between human and nonhuman minds. Behav Brain Sci 31:109–178
Rothenberg A (1971) The process of Janusian thinking in creativity. Arch Gen Psychiatr 24:195–205
Rothenberg A (2015) Flight from wonder: an investigation of scientific creativity. Oxford: Oxford University Press
Runco M, Chand I (1994) Problem finding, evaluative thinking, and creativity. In: Runco M (ed) Problem finding, problem solving, and creativity. Hampton, Norwood, NJ, pp 40–76
Shapiro F (1997) EMDR: eye movement desensitization & reprocessing. Harper Collins Publishers, New York, NY
Sol, D. (2015). The evolution of innovativeness: exaptation or specialized adaptation? In: Animal creativity and innovation. Academic Press, pp 163–187
Sowden PT, Clements L, Redlich C, Lewis C (2015) Improvisation facilitates divergent thinking and creativity: realizing a benefit of primary school arts education. Psychol Aesthetics Creativity Arts 9(2):128–138
Steel M, Hordijk W, Xavier JC (2019) Autocatalytic networks in biology: structural theory and algorithms. J R Soc Interface, 16(151), rsif.2018.0808
Wallas G (1926) The art of thought. Cape, London
Ward TB (1995) What's old about new ideas? In: Smith SM, Ward TB, Finke RA (eds) The creative cognition approach. The MIT Press, pp 157–178