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THE HEURISTIC STRUCTURE OF SCIENTIFIC PRACTICES:

A non-reductionistic account of practices as Heuristic Structures

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1. Introduction. From different disciplinary perspectives, models of culture as a cognitive phenomenon are redrawing the boundaries of the social and the natural sciences, as well as the disciplinary boundaries of philosophy of science and epistemology. The growing importance of the concept of practice in the philosophy of science and epistemology is part of this redrawing of boundaries. The concept of practice, however, has been shrouded in rather obscure formulations. Further progress towards a philosophy of scientific practices requires getting clear about several issues underlying the concept. One important concern is about the best way of explaining how "implicit" or "tacit" knowledge articulated in skills and practices is related to the sort of knowledge that is explicit in scientific theories. This is of course related to the issue of how we understand cognition as a social phenomenon, and to the more general issue of how we model cognition. In this paper I will show how shifting from traditional theories of cognition, based on metaphors of the mind as a computer (and in particular the idea of cognition as, exclusively, manipulation of internal representations), to theories which recognize a more complex and flexible boundary of "internal" and "external" representations, suggest and promotes ways in which the concept of practice can be elucidated and put to work as an important concept in philosophy of science. I will start by giving a brief account of traditional concepts of practice and the problems they face. I will say just enough to show how the difficulties in getting clear on the concept of practice is related with assumptions about the sort of explanation that is needed. Then I give a brief account of the classical view of cognition, and suggest how contemporary models of cognition which abandon the traditional rigid distinction between the internal structure of cognition and the external environment, suggest interesting possibilities which converge with concepts of practice increasingly used in the history of science and the empirical sciences, concepts which rely on a more flexible account about the site of cognition (and thus about the type of representations playing a role in cognition). I will then outline an account of practices which can be seen as supporting and being supported by those accounts of cognition which take seriously the role of external representations. Such account can provide a general framework in which the cognitive and the social aspects of practices can be seen as contributing to the growth of knowledge.

2. **The traditional concepts of practice and their problems.** A well known characterization of practices comes from Wittgenstein. For him "practices are the inherited background against which I distinguish between truth and false". As this quotation suggests, the notion of practice is often found contrasted with that of theory. A practice is something one engages in, consciously or not. The term also refers to the distinctive features of an activity, or to a repeated activity within a relatively well defined context, like the practice of law in a certain country and time. Often the notion of practice is used as a way of referring to the constraining or determination of knowledge by the tools used to reach such knowledge. In some cases it is even suggested, particularly in writings in the history of science, that practices are activities requiring specific tools and subject to certain standards. These notions are not the same. In his book The Social Theory of Practices (Turner 1994) Stephen Turner has introduced a distinction between two major groups of concepts of practice. On the one hand there are those that are based on the model of hidden premises of deductive theories, what he calls "shared presuppositions", and on the other those that refer to embodied knowledge, such as skills, ingrained cultural or moral dispositions, or linguistic competences (Turner 1994, p. 3). Turner criticizes both groups of concepts of practices because, according to him, there is no way in which we can ground the claimed explanatory role of the concept. Since according to him, we do not have direct access to practices, either because the practices are some sort of

cognitive presupposition, or else because practices would be some sort of shared mental structure (which would support the explanation of observed similar behavior), grounding such explanations would require a network of causes described by a theory which would make intelligible the claim. In other words, elucidating the notion of practice would require presenting a theory about mental hidden causes which would explain the phenomena we identify as practices. Such theory is not available. Turner thinks that this lack of direct access leads to another problem, the problem of explaining how practices are transmitted from individual to individual. Practices have to be transmitted, but it is not clear how we can make sense of their transmission. Bordieu, for example, talks of mechanisms of "reproduction of practices", but what are more precisely such mechanisms?[①] Turner thinks that this can only be seen as a metaphor. In order to have a clear idea of how practices get reproduced or transmitted one would need to match them up with the mechanisms familiar to the epistemological tradition – seeing, sensing, the hearing of utterances of linguistic objects such as sentences and the like. After elaborating those problems Turner concludes that the only way one can understand the concept of practice is as individual habits, a notion that can be explained in terms of the usual mechanisms accepted by an individualistic epistemology. After presenting the traditional view of cognition and some alternatives, I will suggest how to answer Turner's worries. The answer will require abandoning the narrow assumptions, associated with the traditional view, about the type of cognition underlying an account of practices. It will involve en particular that we recognize the role that heuristics can play as representations (which cannot be understood as mere internal representations) in cognition.

3. **The traditional view of cognition and its problems.** According to the classical view of cognition the mind is a symbol - manipulating computer which mediates between perceptions (resulting from those traditional mechanisms Turner refers to as those of traditional epistemology) and plans of action. There are several considerations favoring this view of the mind. The processing of information that perceptual systems accomplish seem to fit this view of cognition if, for example, these systems are assumed to work by generating hypotheses about external causes of internal representations which would be the sort of theory . A lot of effort of classical cognitive science has gone into implementations of this idea, which relies on the functional decomposition of the processing task, which in turn reduces to the problem of modeling such systems by finding algorithms that yield the desired output. Nowadays this model of cognition does not seem as convincing as it once did, because of many reasons, but one important reason for sure is related to the fact that there are now alternative models available. Connectionist networks, for example, do not model cognition as a rule - governed manipulation of internal representations, but rather as the result of multi - layered networks which can be trained for solving different tasks. The chief difference between connectionist models and classical ones is that there is no symbolic representation within the network. Representation is rather distributed across the network. Networks have properties that are fascinating from the perspective of a

model of cognition because they turn out to be able to learn in ways similar to the way human beings learn. There is no doubt that connectionist networks are an impressive achievement, as we have already mentioned they are able to mimic important aspects of human thought. But nowadays connectionism is not the only alternative to the classical approach. Dynamical systems theory is another type of project in cognitive science which does not rely on internal representations and centralized processing, it assumes that an agent can be seen as coupled dynamically to an environment in such a way that the need of internal representations and goal directed behavior disappears. Furthermore, there are projects in artificial intelligence which are developing interesting alternatives particularly relevant to our discussion.

Some people working in robotics claim that the only way to achieve artificial intelligence is through building robots that are viable in environments not specified in advance, or constructed in such a way as to suit the perceptual limitations of the robot. Rodney Brooks (1999), for example, started a project from the premise that too much is given away once the programmer presupposes that the system will receive only data of a given type from a given environment[②]. I will focus on this alternative to the traditional account of cognition because it will be easier to make my point. I do not exclude the possibility of arriving to similar conclusions on the basis of connectionist or dynamical accounts. However, I do believe that the sort of models developed by Brooks are particularly relevant since they rely on the notion of activity, a notion that fits very well with an account of practices as something beyond traditional epistemology.

The key difference between the sort of models proposed by Brooks and traditional programs in AI is that instead of looking for a decomposition of a complex problem by functions, he decomposes it in activities. Activities are for Brooks patterns of interactions with the world, such as "exploring interesting – looking areas" or "when passing through a door southbound, turn left". Actions are the result of behavior produced by the direct transformation of input, they are not called as a subroutine by some central program. Thus, there are no global decisions based on centrally held internal representations of the world. As Brooks puts it, the world is the best model[③]. What he proposes is a bottom – up approach to the study of intelligence, as opposed to the top down approach which "tackles intelligence through the notions of thought and reason, things we only know about through introspection" (Brooks p. 134, 1999). As it should be apparent by now, these approaches are useful for elucidating a notion of practice (under the assumption that they are better models of cognition than the traditional ones) to the extent that practices can be understood as articulations of activities. The activities, once they become viable in the (natural) environment get superimposed in what Brooks calls a subsumption architecture. The overall behavior is considered to be the result of various autonomous activities overriding each other. My point here is not to enter a discussion about the merits and problems of the different approaches, but to say that there are scientifically interesting projects which not only do not ground a model of cognition on the manipulation of symbolic representations, but also leave behind the idea that an explanation of cognition has to require a theory about internal representations and the way such representations link inputs and outputs. This is the sort of theory Turner seems to assume it is required to make sense of the notion of practice.

Models which assume the manipulation of internal representations as indispensable for cognition can be called of the "black - box type". Such models assume that it is possible to draw a clear - cut boundary (which plays a crucial role in the explanation) between internal manipulation of representations and external causal processes. Such boundary makes it conceptually impossible to consider whatever causal role the "outside" plays in an explanation of behavior, unless it is mediated by internal representations which get constructed with data coming from perception. Notice, this is the assumption that leads Turner to the conclusion that the only way of making precise the notion of practice is by reducing it to that of habit. Thus, taking seriously alternative approaches to cognition is important for an elucidation of a concept of practice because it suggests ways in which black - box models of cognition can be abandoned, and "external" representational resources can be incorporated into an explanation of the concept of practice. Before going further in our suggestion it is important to address an important objection to all theories which abandon the notion of internal representation as the crux of cognition. The objection arises from the assumption that a theory of cognition has to identify and justify the basic ontology of cognition, the "natural kinds" on which the computational models rest. Internal representations can be identified in terms of functions which in turn can be explained as the result of evolution by natural selection. Thus, it seems that the traditional approach has the support of Darwin's theory, but that any alternative not accepting the central role of internal representations would not have such support.

4. The role of the theory of evolution in a theory of cognition. The core of a theory of cognition is the explanatory relation that is constructed between computational mechanisms and psychological categories. Traditional models of the black box type ground such relation on the notion of internal representation. Natural selection confers scientific legitimacy to functionally derived internal representations, which in turn serve as the basic ontology, the "natural kinds" on which computational models rest. The classical (over) statement of such a view is presented in Dennett's Darwin's Dangerous Idea (Dennett 1995). As Dennett puts it, Darwin's mechanism of natural selection is the "universal glue", it "unifies the realm of life, meaning, and purpose with the realm of space and time, cause and effect, mechanism and physical law"(p. 21). Darwin's dangerous idea – says Dennett – is "reductionism incarnate, promising to unite and explain just about everything in one magnificent vision. Its being the idea of an algorithmic process makes it all the more powerful, since the substrate neutrality it thereby posseses permits us to consider its application to just about anything" (p.82). The way in which Dennett understand Darwin, and it is particularly debatable because the way in which Darwin's idea is turned into an "universal glue" depends on the assumption that we can carve nature (and the mind) at its functions, and this assumption can only be made plausible under other questionable assumptions about the type of explanations that evolutionary theory provides. The assumption, typical of black – box type explanations, according to which the environment has to be understood as having a causal role in biological development only via processes of adaptation is one of these. Another implicit assumption of "incarnated reductionism" is that human rationality was selected for its capacity to lead to certain sort of results, that is, for its function (selecting true beliefs, for example). Daniel Dennett explains this point by saying that natural selection guarantees that most problem solving strategies are rational, in the sense of conforming to logic. Notice that this assumption about the function of rationality has important implications for a theory of practices. If rationality can be modeled as an algorithm then human practices are rational only insofar as they conform to the algorithm, in which case the nature and structure of practices is secondary to whatever concerns we might have about the structure and dynamics of problem solving abilities (what Brooks refers to as "inteligence"). Practices could be only important as part of our psychological structure, and would not be important in the philosophy of science, as part of an effort to understand the normative structure sustaining the growth of knowledge. Practices could be important for understanding the social or psychological basis of science, but would not be important for understanding its "rationality".

But that would require that human rationality can and should be modeled by logic, whereas empirical research points to the fact that human rationality is, at least to a good extent, guided by heuristic rules and biases. What I claim is that the structure of such heuristics is an important part of the structure of "rationality", and thus that the structure of practices is crucial for understanding rationality (see Martinez 2003, Erana and Martinez 2005). To the extent that a certain interpretation of Darwin's theory (and in particular the claim that Darwin's theory allows us to carve nature at its functions) leads to a naturalistic justification of the crucial role of internal representations and to a characterization of rationality as algorithmic, such interpretation is questionable. Implicitly, the claim that function is selected function gets questioned in the cognitive sciences by approaches as that of Brooks. But this identification has been also questioned recently in the philosophy of science and the philosophy of biology in particular. To the extent that, for example, function and design cannot be identified the traditional account in philosophy of biology, as well as its use in the cognitive sciences, is suspect.④ One can argue that Darwin's theory play a crucial role in an account of cognition and rationality without assuming that cognition takes place through manipulation of internal representations and that rationality has to amount to the function of selecting true beliefs⑤. partly because it cannot be assumed that natural selection carve nature at its functions.

In the type of explanation generated by models which are not of the black – box type there is no need of the assumption that we are carving nature at its functions, and thus Darwin's theory does not need to be invoked to provide a link between computational models and models of human cognition. Darwin's theory plays a role in models like the one proposed by Brooks, but not by providing a "universal glue", but rather, by providing the conceptual framework in which the different activities can be understood as emerging from the interaction of an agent with an environment.[6] Patterns of activity can come about through different types of processes, not only natural selection. Thus, in the sort of models proposed by Brooks, evolutionary models continue to play an important role in identifying the basic ontology on which computational models rest, but the story is more complicated, such ontology cannot be characterized as a neatly bounded set of natural kinds which are the result of natural selection. This leads of course to an important problem, the characterization of the alternative natural kinds on which the computational models developed by the cognitive sciences can rest. This is not a trivial matter, it is related with a characterization of what is an "activity". But my point here is not that the sort of model suggested by Brooks does what the traditional model does without its problems, but rather, that the traditional account relies on questionable assumptions, and that independent lines of research point to the need of revising such assumptions in the direction suggested by Brooks.

In biology, the search for a conceptual space in which the environment can be understood as having a causal role in development which is not mediated by adaptation has motivated key discussions about the nature of biological evolution. The recognition of the explanatory power of common history (i.e. evolutionary patterns) is a hard won battle. Notice that such recognition is akin to the recognition of the explanatory power that we can confer to activity patterns. As in the case of explanations grounded on patterns of activity, explanations grounded on common history lead to a questioning of several important similar assumptions about the type of causal explanation one is looking for.

In summary, the incarnated reductionism that Dennett and most philosophers of mind and biology attribute to Darwin depends on a feature of the explanatory model they assume without discussion: that whatever the process to be explained is, it can be abstractly described as requiring a clear – cut distinction between what is inside and what is outside. In the case of cognition this assumption supports the view that functions are associated with goals represented inside the agent, and behavior is understood as requiring those sort of goals to be intelligible. An activity in the sense of Brooks does not require goals to be intelligible, they can be an implicit part of the activity. Nor it requires that goals be represented inside the agent, and thus it suggest a way in which implicit knowledge can be understood as embodied or distributed in the environment, and in the social environment in particular (as we will elaborate in the next section).

Non classical models of cognition, like the model of Brooks, are also important for the elucidation of the concept of practice to the extent that they show how, even though one can recognize the fact that representations are important, we do not need to think of representations as internal links between mental states and actions. Representations can be characterized in terms of material and conceptual resources articulated in standards and norms. Such articulation takes place in the context of practices, and one of the most important tasks facing a philosophy (or a theory) of scientific practices is precisely explaining how such integration takes place as a cognitive process. Before I sketch a proposal in this direction I need to provide some preliminary comments.

Even though I think that reducing practices to individual processes of habituation (as Turner suggests is the only way of making sense of the notion of practice) allows us to understand many practices, and to address several important problems, it is important to realize that there are ways of understanding the social nature of practices which is not in terms of "shared frameworks", or as "cognitive pressupositions" (as Turner seems to assume). I will sketch below a characterization of practice as a heuristic structure. As it turns out this way of understanding practices bypasses the sort of critique elaborated by Turner, and lead us to a better appreciation of the sense in which science is a part of culture. Such account of practices uses the explanatory potentialities of models beyond the black – box type, models which as you remember allow the environment to play a more active role in the shaping of causal explanations. For those readers convinced that the classic black – box account of cognition is the only game in town, the heuristic account of practices would remain shrouded in mystery. So be it.

5. **Scientific practices beyond the black – box model of cognition.** Models of practices in the studies of science that are not of the black – box type have been proposed by many people. Gallison, for example, has developed a concept of scientific practice, subcultures is the word Galison more often uses in this respect, according to which people communicate accross different subcultures through local coordination, not the sort of global translation that is most often associated with the problem of incommensurability. Galison thinks that focusing

on problems of local coordination allow us to overcome what he calls the "island empire picture" according to which science is divided in "island empires", each of which encompasses a relatively consistent assembly of experimental and theoretical procedures and results. Variously designated as frameworks, conceptual schemes, and paradigms, each such islet of knowledge supports its own language; (p. 13, Buchwald 1995).

In order to characterize these subcultures Galison introduces the notion of constraint. Constraints are meant to mark the boundaries of reasonableness. Thus they function as biases marking what is worth investigating, or what is possible. They can also refer to common knowledge of materials or techniques, or to ways of applying basic theoretical principles, like conservation laws or symmetries. Clusters of constraints, think Galison, carve out different subcultures of science, distinguishing the standards of proof and experimental correctness proper of a given subculture, for example. Thus, Galison is promoting a notion of practice that goes beyond the model of practices as grounded on shared presuppositions, and rather promotes a notion of practice going beyond the black - box model: the language of constraints allows one to consider a scientific problem setting in its own terms - ones that cut across an after - the fact classification into the "internal" and the "external". The different subcultures learnt to communicate by constructing bridge - languages, what following standard usage in anthropology, Galison calls "pidgin" and "creole". These are the sort of languages that arise in the border zones between different theoretical, experimental or engineering cultures.⑦ Thus, Galison clearly distances himself of the idea of practice as “shared framework” and from a black - box type of explanation of scientific activity.

The notion of constraint of Galison is closely related to the notion of of activity used in models of cognition of subsumption architecture. Galison talks of constraints as what marks the limits of action within a given subculture very much in the same sense that marks in the environment generate emerging patterns of activity in models of the type promoted by Brooks. The connection between these two concepts of mark can be made tighter if one notice that both notions can be related to the notion of cognitive bias familiar from the literature on heuristic reasoning. A bias marks the boundary in which a given heuristic rule gives us a reliable answer, or points to the sort of cases in which the rule is considered to apply reliably. A heuristic rule is the one that lead us to infer that a city A is bigger than another city B because we know A has a soccer team, whereas B does not. In certain circumstances, if we are referring to cities in Africa, for example, it will not be a good inference. If we apply the heuristic rule in question only for cities in Europe then the rule will work rather well. Thus, it is clear that the bias marks the boundary of what is reasonable to infer. Thus, this notion of cognitive bias can be seen as representing the sort of bias introduced by Galison through the notion of constraint, as well as the notion of mark used as a representation of the world in the sort of cognitive models proposed by Brooks. Here I cannot develop this important point further, but I hope that the main point is clear: abandoning the black - box model of cognition, allows to see connections between models of cognition and notions of practice that are productively used in the studies of science, and to the notion of heuristic which as we shall see stands at the center of a notion of practice.

Models of cognition that are not of the black – box type incorporate concepts like those of constraint (in an active sense), activity or "situated action" that lend themselves to be used productively in the interphase between the cognitive and the social sciences, or at least in the formulation of senses in which practices are social that go beyond the idea of "shared framework". Jean Lave initiated a project for understanding cognition in practice which is worth mentioning now as an example of a model of cognition which is not of the black – box type, and which clearly points to a notion of practice articulated in terms of heuristics.⑧ It is often assumed that our mastering of arithmetical practices is directly related with our competence in the use of arithmetical algorithms taught in school. So, it is assumed that what we have to learn in order to master arithmetic is an algorithm that would manipulate the internal representations we construct of a given problem in which the algorithm can be applied. The different situations are considered merely as data (or data providers) which enters as input in the algorithm. Work in the 1980′s by Lave and collaborators questions seriously this view. Their studies establish that knowledge of the arithmetical algorithms, years of school, and several other factors associated to what would be usually understood as a deeper learning of the algorithms do not impinge much in the capacity for comparing prices in a supermarket. Most people use for this purpose heuristic rules of the type know as calculations from left to right, by which a number is decomposed in centens, decens and units. The use of such rules usually takes in consideration that we can make a mistake, and so we monitor their use with other heuristic rules that allow us to detect a wrong inferences. For example, we can use transitivity and a known price per kg to know whether a price we are checking is high or low. As it is to be expected, the way in which a problem is decomposed into subproblems which in turn are solved by heuristic rules is quite variable and points to the conclusion that our arithmetical practices cannot be understood by what we are taught in school about the arithmetical algorithms. One has to try to understand how the standards used in practice come about through the alignment of cognitive and material resources which generate a "pidgin" type of understanding of a situation which can turn into a sophisticated method, or remain as a rather hard to pinpoint type of heuristic. Next I present an account of practices as heuristic structures that can help us to model this sort of processes, and to profit from the convergences about different notions of bias we mentioned earlier.

5. Practices as Heuristic Structures. A heuristic rule is some sort of strategy for the solution of problems, or the drawing of inferences of a given sort which does not lead to a guaranteed solution or to a guaranteed good inference. In some cases the rule can be very helpful in allowing us to find a solution or draw an inference in a very fast way, but in some cases the rule misleads us. One says that a heuristic has a distinctive bias, which is a way of recognizing that the heuristic leads reliably to solutions in some situations and systematically to wrong so-

lutions in others. For example, it is well known that we tend to make probabilistic reasonings using heuristics, which in some cases lead to systematic biases. A famous example is the bias of human beings to neglect base rates in probabilistic thinking. A heuristic structure is a collection of heuristic rules and skills that are systematically related through norms and standards, allowing us to solve problems and transform features of material and conceptual systems. Such articulation of heuristics, skills, norms and standards, as part of a specific cultural context, constitute what I call a practice. Institutionalization, particularly in science, often promotes the stabilization of norms and standards and thus tend to increase the relialability of the heuristic rules and an understanding of the biases, and thus the scope, of different heuristic structures. One example of a heuristic structure in science is a laboratory technique. As it has been well documented by empirical studies, a laboratory technique often starts as a way of carrying out a task which is hardly reliable outside given circumstances which are not easy to pinpoint abstractly (or propositionally). Often, as time passes, variants of the technique are found that are more easily exported. But always an important part of the claim that we master a technique is our ability to identify the situations in which the technique work and the situations in which it doesn't (see chapter 4 of Martinez 2003). Another example of a heuristic structure is the type of techniques that a physicist learn to model types of situation as applications of a given differential equation. To learn to use Schrodinger's equation is more like learning to apply arithmetic in different situations in ordinary life, than learning to apply an algorithm. Learning quantum mechanics is learning heuristic structures allowing us to construct the sort of models which are considered appropriate, according to standards of a given practice. The theoretical framework of quantum mechanics is associated with different practices. It is associated with learning and teaching practices associated with standard courses, with laboratory practices, and with practices of different specialized fields. Quantum mechanics is not the same for someone working in general relativity and someone working in elementary quantum physics. The way of framing problems, or establishing relations with other practices is importantly different in some cases, and that leads to well known biases in the way in which different specialties understand quantum mechanics.

If cognition can be modeled successfully by models of the black - box type then practices and heuristic structures cannot play any significant cognitive role. But if cognition is modeled by models which are not of the black - box type, for example by models like those proposed by Brooks, then practices can be easily incorporated as an essential part of the model. heuristics can be understood as modeling patterns of interaction with the world. If our mastering of arithmetic were to be modeled by models of the black - box type then such mastering could only consist in learning well how to apply the algorithms of arithmetic in any logically possible situation. Success in the real world would be understood to be a consequence of such mastering. But does not seem to be how our cognition works, we rather often use biases or constraints to identify types of situations in which we apply specific heuristic rules. Heuristic rules are not applied as part of a centralized plan, they are applied rather in a piece－meal fashion, in the relevant situations. Heuristics, biases, standards and norms can generate quite complex structures which are articulated not merely by "internal" assumptions or shared beliefs, but by a subsumption architecture which includes the structure of the environment essentially, as part of the representational resources of cognition and action. In this sense a practice is a complex array of resources, including norms, representations and heuristics, distributed in social structures or institutions.

Notes:

① see for example Bordieu 1972. Pierre Bordieu, Esquisse d′une théorie de la pratique, 1972 Librairie Droz, Geneve.

② Brooks, R. A. 1991, "Intelligence without Representations", Artificial Intelligence 47: 139～160. Also appeared in Luger 1995. "Intelligence without Reason" in Int. Joint Conference on Artificial Intelligence, pp. 569～595. Also appeared in Steels and Brooks 1995. It is important to point out that, in spite of the title of Brooks 1991, his claim is not that intelligence can proceed without representations, but only that intelligent behavior can be generated without appealing to explicit manipulable internal representations. See also, Horst Hendriks－Jansen 1996.

③ A very good characterization of Brooks project particularly relevant for want I am saying here is Hendriks－Jansen1996 (particularly chapter 8). Hendriks－Jansen emphasizes the importance of the concept of activity in Brooks account.

④ See for example "biological Function, Adaptation and Natural

Design", by Colin Allen and Marc Bekoff, Philosophy of Science 62 (1995), Amundson R. and Lauder Gf. 1994 "Funtion without Purpose: The uses of causal role in evolutionary biology" in Biology and Philosophy, 9, 443~469.

⑤ See for example Matthen 2002.

⑥ See Hendriks-Jansen 1996.

⑦ Here is Galison: " Moving away from the stack periodization typical of conceptual schemes, radical translations, gestalt switches, and paradigm shifts comes at a price: we lose the vivid metaphorical imagery of totalistic transformations. In the place of such all-or-nothing mutations we need some guidance in thinking about the local configurations that are produced when two complex sociological and symbolic systems confront one another. Anthropologists are familiar with such exchanges, and one of the most interesting fields of investigation has been the anthropological linguistics of pidginization and creolization; I have used these ideas throughout the preceding chapter to characterize the border zones between different theoretical, experimental, and engineering cultures. Both terms - "pidgin" and "creole" - refer to languages at the boundary between groups. A pidgin usually designates a contact language constructed with the elements of at least two active languages; "pidginization" is the process of restriction by which a pidgin is produced. By convention, "pidgin" is not used to describe a language that is used even by a small group of people as their native tongue. A creole, by contrast, is a pidgin extended to the point where it can serve as a reasonably stable native language" (p. 832, Image and Logic).

⑧ See Jean Lave Cognition in Practice, 1988, Cambridge.

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