

Conceptual Revolutions: From Cognitive Science to Medicine

Conceptual Revolutions: From Cognitive Science to Medicine

Edited by WENCESLAO J. GONZALEZ

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Wenceslao J. Gonzalez

CONCEPTUAL REVOLUTIONS: FROM COGNITIVE SCIENCE TO MEDICINE

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www.netbiblo.com

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Member of European Union Publishers' Forum

ISBN: 978-84-9745-933-4

Legal Deposit: C-3161-2011

Editorial Manager: Cristina Seco López

Editor: Paola Paz Otero

Production Management: Gesbiblo, S. L.

Cover Design: Jéssica Rey

First Published 2011 by Netbiblo, S.L.

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Prologue

PROLOGUE

Wenceslao J. Gonzalez

Conceptual Revolutions deals with the issue of revolutions in science due to “internal” factors rather than to “external” components. The book assumes that history of science has shown us the existence of deep changes in scientific activity, and the aim is to characterize them properly. In this regard, the emphasis is here on the analysis of concepts used by scientists rather than on contextual aspects of scientific research (social, cultural, economic, political, etc.). *De facto*, this characterization of revolutions in terms of variations in concepts supposes an alternative view to Thomas Kuhn’s approach to scientific revolutions.

The configuration of the book underlines two scientific realms — cognitive science and medicine — because of their relevance nowadays for conceptual revolutions. On the one hand, cognitive science has a leading role in the analysis of concepts in scientific activity, and, on the other, medicine is a dominion where the scientific changes have been particularly deep in recent decades. The subtitle — *From Cognitive Science to Medicine* — emphasizes the existence of a thematic transition in this volume from the first realm to the second one.

Certainly, these scientific disciplines are especially important in order to discuss conceptual changes in science that lead to revolutions. They receive particular attention in the five sections of the book, which involves ten chapters. The volume starts with the most general topic: conceptual revolutions and complexity. Thereafter, it moves on to specific issues in cognitive science and medicine as well as in new sciences. The kind of problems discussed here are mainly contemporary ones. Thus, there are many aspects that have not been analyzed in Kuhn’s volume *The Structure of Scientific Revolutions*.

This new book on *Conceptual Revolutions* is another step in the discussion on contemporary problems in philosophy and methodology of science. The contents of this volume are at the core of the topics analyzed in this series published by Netbiblo under the label of *Serie de Filosofía y Metodología de la Ciencia/Philosophy and Methodology of Science Series*. These volumes have their roots at the University of A Coruña, which organizes every year a conference on these issues (*Jornadas sobre Filosofía y Metodología actual de la Ciencia*). In fact, most of the papers of the present book were delivered in a conference there, at the Ferrol Campus, where the main speaker was Paul Thagard.

Undoubtedly, this series on philosophy and methodology of science has interest internationally, but it has its own character within the framework of academic standards. In addition, this series is published by Netbiblo, a publishing house that has had a particular focus of attention on the Internet from the very beginning. Thus, it is keenly aware of the new possibilities open up by the World Wide Web. From the thematic point of view, contemporary issues have been central for this publisher ever since. In this regard, this house has published books on these topics of contemporary philosophy since 2003.

Initially, the books were in Spanish, such as *Racionalidad, historicidad y predicción en Herbert A. Simon*, 2003. After two years there were a set of volumes published in English: *Science, Technology and Society: A Philosophical Perspective*, 2005; *Contemporary Perspectives in Philosophy and Methodology of Science*, 2006; *Evolutionism: Present Approaches*, 2008; and *New Methodological Perspectives on Observation and Experimentation in Science*, 2010. These books have a key role in this series on philosophy and methodology of science. Commonly, these volumes look for an enlarged vision of the field and they are oriented towards originality.

Macclesfield, UK, 15 August 2011

I

Conceptual Revolutions and Complexity

1. The Problem of Conceptual Revolutions at the Present Stage
2. Conceptual Changes and Scientific Diversity: The Role of Historicity

THE PROBLEM OF CONCEPTUAL REVOLUTIONS AT THE PRESENT STAGE

Wenceslao J. Gonzalez

Science has structural and dynamical features. Thus, besides the components that constitute any contemporary science (language, knowledge, method, etc.), there are “internal changes” in science as well as changes due to “external” factors. In the case of the “internal” traits, the changes that are most noticeable are those related to theoretical, empirical and heuristic aspects. Meanwhile the changes as a result of “external” factors are mainly those of contextual character: they are social, economic, ecological, political, etc.¹ These internal and external facets give rise to a scientific dynamics that has peculiar characteristics in each science.

Conceptual changes are in the core of the “internal changes.” They have a role in the theoretical, empirical and heuristical changes in science which connect with scientific discoveries and evaluations. Those changes have been described in different ways, among them the evolutionary terms and the revolutionary forms. Thus, after several decades of the twentieth century emphasizing the scientific progress as a sort of evolutionary process (either as an accumulative process based on empirical grounds or as an epistemology of selection of theories), the emphasis went to the revolutionary analysis. This was noticeable in 1962, when Thomas Kuhn offered a revolutionary approach on scientific change.²

This very influential conception received a full-fledge alternative, which was focused on conceptual revolutions instead of relying on scientific communities that change paradigms from time to time. This cognitive orientation on concepts was presented by Paul Thagard in 1992,³ although the expression “conceptual revolutions” was not new then.⁴ Nowadays — almost two decades after his book — the attention is paid to new aspects regarding conceptual revolutions. This vision includes recent developments in cognitive sciences, mainly those involving the contributions of neuroscience, but it also contains new perspectives on important sciences, such as medicine. Following these lines, the present volume pays attention to topics that have not been among the “traditional” issues of philosophy and methodology of science.

¹ The contextual dimension requires to take into account the institutions, i.e., the research centers and their values. On this issue of “internal” traits and “external” factors, see GONZALEZ, W. J., “Trends and Problems in Philosophy of Social and Cultural Sciences: A European Perspective,” in STADLER, F., DIEKS, D., GONZALEZ, W. J., HARTMAN, S., UEBEL, TH. and WEBER, M. (eds.), *The Present Situation in the Philosophy of Science*, Springer, Dordrecht, 2010, pp. 221-242; especially, pp. 222-223.

² Cf. KUHN, TH. S., *The Structure of Scientific Revolutions*, The University of Chicago Press, Chicago, 1962 (2nd ed., 1970). Paradoxically, the book was published as “International Encyclopedia of Unified Science: Foundations of the Unity of Science,” vol. 2, n. 2.

³ Cf. THAGARD, P., *Conceptual Revolutions*, Princeton University Press, Princeton, 1992.

⁴ See for example TOULMIN, S. E., “Conceptual Revolutions in Science,” *Synthese*, v. 17, (1967), pp. 75-91. The novelty was in the cognitive approach developed by Thagard.

Below is the framework for the contents of this book as well as the main bibliographical references regarding the topics discussed. The first section of this chapter pays attention to the characterizations of “scientific revolutions” in Kuhn’s successive approaches to this topic, of which the most famous is the initial one. Thereafter, the analysis moves to the coordinates of Thagard’s “conceptual revolutions,” which can be found in the book of the same title. This is followed by the consideration of new philosophical-methodological aspects on the same topic. In the second section there is an explanation of the origin and main features of the present book. As a complement to both sections, the third one makes the relevant bibliography about conceptual revolutions explicit, which is articulated at three levels: i) scientific change (i.e., historicity, evolution, and revolution), ii) revolutions in science, and iii) conceptual change and conceptual revolution.

1. FROM SCIENTIFIC REVOLUTIONS TO CONCEPTUAL REVOLUTIONS

Certainly Kuhn was not the first author in considering “revolutions” in science,⁵ but he was extremely influential with his proposal of “scientific revolutions” based on paradigms that shift due to scientific communities. Nonetheless, his well-known philosophical-methodological conception of the “scientific revolutions” — and his views on “incommensurability” — evolved. Moreover, he offered us *de facto* three characterizations of them. In this regard, he moved from a radical view of the initial approach to a clearly moderate perspective of a third stage, making a second analysis of scientific revolutions in between, as can be seen on analyzing his texts.⁶

On the one hand, Kuhn always defended the *existence* of scientific revolutions as a historical event. He exemplified this aspect on historical bases, developing several case studies, such as the Copernican revolution. And, on the other hand, his proposal was inserted into a wider intellectual approach. His view was based on the search for a philosophical-methodological *characterization* of scientific endeavors in tune with history of science, in order to avoid a reflection that is distant from the actual scientific activity. According to this perspective, the Kuhnian thematic axis relies on the articulation of history of science with philosophy and methodology of science. But his philosophical-methodological perspectives, those that he proposed to analyze historical cases, varied clearly under the influence of criticisms that he received.

1.1. Kuhn’s Scientific Revolutions

Ever since 1962, Kuhn has been linked to the contents of *The Structure of Scientific Revolutions*. But after his book on scientific revolutions, he developed two additional philosophical-methodological conceptions that involve a reflection on “scientific revolutions.” Initially, although he was in favor of “internal” traits in science, the main forces for changes seemed to be *contextual* rather than conceptual. Thus, during the revolutionary periods after a scientific crisis, the scientific communities had a “conversion” from one paradigm to a new

⁵ Cf. MACHAMER, P. K., “Las revoluciones de Kuhn y la Historia ‘real’ de la Ciencia: El caso de la revolución galileana,” in GONZALEZ, W. J. (ed.), *Análisis de Thomas Kuhn: Las revoluciones científicas*, Trotta, Madrid, 2004, pp. 253-273; especially, pp. 253-254.

⁶ A detailed analysis of Kuhn’s conception(s) of the “scientific revolutions” and his three philosophical-methodological periods is in GONZALEZ, W. J., “Las revoluciones científicas y la evolución de Thomas S. Kuhn,” in GONZALEZ, W. J. (ed.), *Análisis de Thomas Kuhn: Las revoluciones científicas*, pp. 15-103. This text is used for the present section, especially for the contents of 1.1).

one. Then, through that drastic process, the scientific content suffered a severe change that led to incommensurable paradigms.

Revolutions were in his initial view subsequently more community-driven than conceptually focused. The consequence of Kuhn's original proposals was to put the methodology of science in a precarious situation (there were intrinsic difficulties for the methodological rules) and to see the development of scientific theories — in particular, the revolutionary cases — as a psycho-sociological change rather than a coherent activity. Thus, although *The Structure of Scientific Revolutions* has been very influential, the issue itself of the “scientific revolutions” seemed to be controversial in his first presentation.

Nowadays, it is increasingly frequent to distinguish *three main phases* in Kuhn's intellectual trajectory on philosophical-methodological issues.⁷ They are periods of *intellectual evolution* that are closely related to his analysis of “scientific revolutions.” In addition, the phases are connected with the issue of “incommensurability” (a phenomenon that, for him, happens between scientific theories that belong to two different ways of doing science — those modes involved in two distinct “paradigms:” the old and the new —). These stages in his thought have no standard denomination, but the contours are — in my judgment — well defined and present characteristic features that allow differences to be established.

1) Initial period of a *philosophical-methodological configuration*: it embraces from the preliminary works to *The Structure of Scientific Revolutions*, until approximately 1968.⁸ One of its central elements is the duality “normal science”-“revolutionary science,” where a key factor is the analysis of “paradigms.” This will influence on the posterior course of the “historical turn” in philosophy and methodology of science. The main contribution is the book *The Structure of Scientific Revolutions*, which contains his well-known methodological views and the strong version of his thesis regarding paradigms, scientific revolutions, and incommensurability. This part of his intellectual trajectory has received the largest number of criticisms. Most of them are objections related in one way or another to relativism and irrationalism.

2) Period of *revision, clarification and enlargement* of the initial theses: it starts around 1969 and reaches at least the 1970s (the ingredients of the following phase are most visible at the beginning of the 1980s, especially after the *Philosophy of Science Association* conference in 1982). The stage begins with two well-known papers: *Postscript—1969*,⁹ which is included in the second edition of *The Structure*, and his contribution to the conference in Urbana (Illinois) in March 1969: *Second Thoughts on Paradigms*.¹⁰ Both arose with the intention of clarifying his initial theses but ended up changing them. He tried to meet the criticism of the first period. To this revisionist phase belong several papers, such as his responses of 1970 to the objections presented in the conference in London of 1965 — *Reflections on My Critics* —¹¹ and several essays

⁷ An interesting case in this regard is IRZIK, G., “Thomas Kuhn: The Road Since *Structure*,” *Philosophy of Science*, v. 68, n. 4, (2001), pp. 573-575; especially, p. 574.

⁸ If we interpret Kuhn literally regarding the time spent on maturing of *The Structure of Scientific Revolutions* — 15 years —, then the initial period of his thought started towards the end of the 1940s.

⁹ KUHN, TH. S., “Postscript—1969,” in KUHN, TH. S., *The Structure of Scientific Revolutions*, 2nd ed., pp. 174-210.

¹⁰ KUHN, TH. S., “Second Thoughts on Paradigms,” in SUPPE, F. (ed.), *The Structure of Scientific Theories*, University of Illinois Press, Urbana, 1974 (2nd ed., 1977), pp. 459-482; reprinted in KUHN, TH. S., *The Essential Tension*, The University of Chicago Press, Chicago, 1977, pp. 293-319.

¹¹ KUHN, TH. S., “Reflections on My Critics,” in LAKATOS, I. and MUSGRAVE, A. (eds.), *Criticism and the Growth of Knowledge*, Cambridge University Press, Cambridge, 1970, pp. 231-278.

collected in *The Essential Tension*, where the paper *Objectivity, Value Judgment and Theory Choice*¹² should be emphasized insofar as he enlarges his conception with new elements.

3) New creative phase of *linguistic character*: it is noticeable since 1982, the year of his famous contribution to the PSA conference: *Commensurability, Comparability, Communicability*,¹³ and it extends until his final days in 1996.¹⁴ The main thread is the emphasis on scientific language, and so it also called as *linguistic turn*. The interest is in the processes of learning a language, insofar as they can affect the scientific revolutions and incommensurability. He pays attention to the proposals of the causal theory of reference defended by Hilary Putnam and Saul Kripke.¹⁵ These views are considered from the perspective of the relations between translations and incommensurability (now understood in a local sense).¹⁶ This phase also known for its taxonomic lexicons has as a relevant book *The Road Since Structure*, which was published posthumously.¹⁷

Each step of this intellectual trajectory can be seen from the angle of the “scientific revolutions.” Moreover, looking from the perspective of *scientific revolutions*, three philosophical-methodological stages can be distinguished in Kuhn. They are related to the phases of his conception already mentioned. i) Scientific revolutions as epistemological and ontological modifications, because they affect the worldview and, even more, the world itself studied (*world-changes*).¹⁸ These revolutionary variations involve changes in the perception of reality (*Gestalt switches*) and the need for psycho-sociological decisions (*conversions*) for choosing between paradigms, insofar as there is a neat *incommensurability* between the old paradigm and the new one. ii) Revolutions as generators of incommensurability between what was previously accepted and the new proposal. Now there is the possibility of *comparability*, insofar as there are “good reasons” to select theories: they are the values of accuracy, simplicity, fruitfulness, consistency and scope. iii) Scientific revolutions as different *linguistic frameworks*, which includes the problem of translation (a partial impossibility of translation, in principle). Thus the taxonomic lexicons and the processes of learning a scientific language make the incommensurability “local” instead of “global.”

¹² KUHN, TH. S., “Objectivity, Value Judgment and Theory Choice,” lecture at the University of Furman on 30 November 1973. Reprinted in KUHN, TH. S., *The Essential Tension*, pp. 320-339.

¹³ KUHN, TH. S., “Commensurability, Comparability, Communicability,” in ASQUITH, P. D. and NICKLES, TH. (eds.), *Proceedings of the 1982 Biennial Meeting of the Philosophy of Science Association*, vol. 2, Philosophy of Science Association, East Lansing, MI, 1983, pp. 669-688. Reprinted in KUHN, TH. S., *The Road Since Structure*, The University of Chicago Press, Chicago, 2000, pp. 33-53.

¹⁴ There is also an unpublished book related to incommensurability, which was written in his last years. It is a book that Kuhn himself and other authors have referred to.

¹⁵ Cf. KUHN, TH. S., “Dubbing and Redubbing: The Vulnerability of Rigid Designation,” in SAVAGE, C. W. (ed.), *Scientific Theories. Minnesota Studies in the Philosophy of Science*, v. XIV, Minnesota University Press, Minneapolis, 1990, pp. 298-318.

¹⁶ KUHN, TH. S., “Remarks on Incommensurability and Translation,” in ROSSINI FAVRETTI, R., SANDRI, G. and SCAZZIERI, R. (eds.), *Incommensurability and Translation: Kuhnian Perspectives on Scientific Communication and Theory Change*, Edward Elgar, Cheltenham, 1999, pp. 33-37.

¹⁷ *The Road Since Structure* was published in 2000 by the University of Chicago Press with a clear subtitle: *Philosophical Essays, 1970-1993, with an Autobiographical Interview*.

¹⁸ The first aspect — the epistemological one — is a *change in worldview*: “paradigm do cause scientists to see the world of their research-engagement differently,” KUHN, TH. S., *The Structure of Scientific Revolutions*, 2nd ed., p. 111. The second possibility — the ontological one — is a *change in worlds* focused by paradigms: “when paradigms change, the world itself changes with them,” *The Structure of Scientific Revolutions*, 2nd ed., p. 111.

I) There is in *The Structure of Scientific Revolutions* a new vision of the dynamics of scientific development. In this dynamics, the articulation in terms of “progress” is, in principle, problematic. It is supported by an interpretation of history with two fundamental historiographic categories: “normal science,” which involves the continuity in the paradigm, and “revolutionary science,” which implies “non-cumulative developmental episodes in which an older paradigm is replaced in whole or in part by an incompatible new one.”¹⁹ This distinction was soon the object of a number of analyses of philosophical kind.²⁰ But the book is rather a *historiographical essay* than a volume of philosophy and methodology of science.²¹

However, Kuhn offers here a *dynamics of scientific development* without a well-defined methodological characterization.²² Clearly, his approach of scientific development is not a linear process: a paradigm conforms the endeavor of normal science, which has to deal with the resolution of scientific puzzles — the activity of *puzzle-solving* — and needs to elucidate the anomalies generated through the research. A crisis may then show up, due to the dissatisfaction with the available paradigm regarding the results in the scientific problem solving. This leads to the overlapping of the old and new paradigm,²³ which is followed by the revolution: the substitution of the old paradigm by a new one, incompatible with the previous paradigm. And this gives way to a new period of normal science. To some extent, we can find here something similar to a political revolution.²⁴

Through the scientific revolution there is a deep change: several levels are modified. Among them are the epistemological and methodological spheres, which have repercussions on the ontological realm. According to Kuhn, in the case of science, “led by a new paradigm, scientists adopt new instruments and look in new places. Even more important, during revolutions scientists see new and different things when looking with familiar instruments in places they have looked before. (...) [P]aradigm changes do cause scientists to see the world of

¹⁹ Cf. KUHN, TH. S., *The Structure of Scientific Revolutions*, 2nd ed., p. 92.

²⁰ Karl Popper was among those that dealt with the first one in the conference of 1965: POPPER, K. R., “Normal Science and Its Dangers,” in LAKATOS, I. and MUSGRAVE, A. (eds.), *Criticism and the Growth of Knowledge*, pp. 51-58. Later he discussed the second one: POPPER, K. R., “The Rationality of Scientific Revolutions,” in HACKING, I. (ed.), *Scientific Revolutions*, Oxford University Press, Oxford, 1981, pp. 80-106.

On the “Popper-Kuhn controversy” see WORRALL, J., “Normal Science and Dogmatism, Paradigms and Progress: Kuhn ‘versus’ Popper and Lakatos,” in NICKLES, TH. (ed.), *Thomas Kuhn*, Cambridge University Press, Cambridge, 2003, pp. 65-100.

²¹ Alexander Bird has called attention to this: “*The Structure of Scientific Revolutions* is primarily something other than philosophy — of the 150 footnotes in the first edition of that book, only 13 include references to philosophers, and almost all of these are to philosophers whose views are in tune with Kuhn’s (the vast bulk of the remaining references are to historians),” BIRD, A., *Thomas Kuhn*, Acumen, Chesham, 2000, pp. ix-x.

²² The succession of periods of normal science followed by other periods of revolutionary science is based on the idea of continuity of a paradigm — the first case — and the acceptance of a new and completely different paradigm (the second case). But the “paradigm” itself does not offer a well-defined methodological pattern. Later Kuhn himself was aware of the congenital weakness of his initial proposal.

²³ “The transition from a paradigm in crisis to a new one from which a new tradition of normal science can emerge is far from a cumulative process, one achieved by an articulation or extension of the old paradigm. Rather it is a reconstruction of the field from new fundamentals, a reconstruction that changes some of the field’s most elementary theoretical generalizations as well as many of its paradigm methods and applications. During the transition period there will be a large but never complete overlap between the problems that can be solved by the old and by the new paradigm,” KUHN, TH. S., *The Structure of Scientific Revolutions*, 2nd ed., pp. 84-85.

²⁴ In fact, Kuhn establishes two parallelisms between scientific revolutions and political revolutions. Cf. *The Structure of Scientific Revolutions*, 2nd ed., pp. 92-94.

their research-engagement differently. In so far as their only recourse to that world is through what they see and do, we may want to say that after a revolution scientists are responding to a different world.”²⁵

Among the characteristic features of the Kuhnian *scientific revolutions* are the following. First, the existence of *world-changes* is accepted. This involves two sides: a) the epistemological modification in grasping how the world is, where the revolution brings a *different vision* on what there is, even though the actual phenomena be the same;²⁶ and b) an ontological alteration, insofar as there is a change *in the world* whose study focuses the attention of scientists.²⁷ Second, there are variations regarding perceptions — *Gestalt switches* — because the agents — the scientists — perceived diversely the form (*Gestalt*) after the revolution. Thus, there is *no stable image* of the scientific reality known: each revolutionary period brings its own image. Third, the decision making of scientists is undergoing radical variations, due to its psychosocial character. According to this assumption, there are *conversions* to the new paradigm instead of rational processes with no standard criteria. Thus, instead of giving the primacy to the logical component or to the experience as such, Kuhn conceives the decisions to choose between paradigms in a revolution as psycho-sociological.

II) During the second period two ideas on “paradigms” of the initial stage remain. They are the global use and the particular utilization. “Disciplinary matrix” corresponds to the first one, insofar as it includes all the elements shared; meanwhile “exemplars” develop the second task. The *revision, clarification and enlargement* of Kuhn’s thought is noticeable: the original idea of paradigms saw them as *examples* of success in the scientific practice that are accepted by the community (i.e., the second function); but he recognizes that he went too far in embracing *all* shared group commitments, all components of what he calls now as the *disciplinary matrix* (i.e., the first mission). “Inevitably, the result was confusion, and it obscured the original reasons for introducing a special term. (...) Shared examples can serve cognitive functions commonly attributed to shared rules.”²⁸

What are then the scientific revolutions in this second period of Kuhn’s approach? It might be inferred that, in this stage, they are the radical changes operated in the disciplinary matrices, in general, and in the exemplars, in particular. But the scientific revolution is now primarily *linguistic* rather than predominantly epistemological and methodological. At this point, there is a break in the communication and each part recognizes the other as a member of a different linguistic community. Thus, they become translators.²⁹ This involves a new conception of incommensurability, where the paradigm is a linguistic whole that is in front of another linguistic set. Thus, “each will have learned to translate the other’s theory and its consequences into his own language and simultaneously to describe in his language the world to which that theory applies. That is what the historian of science regularly does (or should) when dealing with out-of-date scientific theories.”³⁰

²⁵ KUHN, TH. S., *The Structure of Scientific Revolutions*, 2nd ed., p. 111.

²⁶ “Though the world does not change with a change of paradigm, the scientist afterward works in a different world.” KUHN, TH. S., *The Structure of Scientific Revolutions*, 2nd ed., p. 121.

²⁷ Cf. KUHN, TH. S., *The Structure of Scientific Revolutions*, 2nd ed., p. 111.

²⁸ KUHN, TH. S., “Second Thoughts on Paradigms,” p. 319.

²⁹ In this regard, Kuhn is thinking of the reflections on translation made in QUINE, W. V. O., *Word and Object*, The MIT Press, Cambridge, 1960, chapters I and II, pp. 1-25 and 26-79.

³⁰ KUHN, TH. S., “Postscript—1969,” p. 202.

III) A new step is in the “linguistic turn” of the third period, which involves several differences from the previous stage.³¹ 1) Kuhn considers now that each theory has its own *lexicon*. It is a network that has the *kind-concepts* or the *kind-terms* taxonomically ordered, which have reciprocal relations. 2) Scientific revolutions are characterized in this third period as relevant changes in the *lexicons* instead of paradigm-shifts. 3) The old distinction between “normal science” and “revolutionary science” is now a difference between activities that do not require changes in the lexicon and those that do. Then, the description of scientific revolutions as *Gestalt switches* disappears. 4) In this stage, “incommensurability thus becomes a sort of untranslatability, localized to one or another area in which two lexical taxonomies differ.”³² Because it is a local phenomenon, there is no incomparability. To understand a theory is not to translate it into one’s language, as W. van O. Quine’s suggested,³³ but rather to acquire a new language, which means to be bilingual. 5) The diverse languages structure the world differently. Thus, lexicons acquire the function of paradigms regarding the world and experience.

Therefore, in this stage of emphasis on language, scientific revolutions lack the radicalism of the first period, where there is incommunicability between paradigms. In addition, they do not require the global linguistic character of the phase of revision, where the task is to be a translator to communicate a disciplinary matrix with another one. Now, in the stage of the “linguistic turn,” scientific revolution does not make impossible the reciprocal understanding of the contents of the alternative proposal: there are concrete difficulties of translatability that are overcome through learning to be bilingual. For Kuhn, “members of one community can acquire the taxonomy employed by members of another, as the historian does in learning to understand old texts. But the process which permits understanding produces bilinguals, not translators.”³⁴

By means of the reduction of scientific revolutions to some difficulties in translatability — within an incommensurability of “local” character —³⁵, there is a noticeable decrease in the relativist nature of the texts of the initial period. In fact, the original incommunicability and incomparability are dismissed: the revolution only involves difficulties in translation, which should not be seen as a “linguistic relativism.” Moreover, instead of supporting the excesses of the “strong program,” Kuhn recognizes now the need for the notion of “truth.”³⁶ He does so in the presidential address to the *Philosophy of Science Association*, where he points out that “properly understood — something I’ve by no means always managed myself — incommensurability is far from being the threat to rational evaluation of truth claims that it has frequently seemed.”³⁷

Explicitly, Kuhn deals with scientific revolutions in a monographic essay: *What are Scientific Revolutions?*³⁸ He revisits the distinction of the initial period, i.e., “normal science” — “revolutionary science.” The first expression appears as research that adds something to the

³¹ These differences are pointed out in IRZIK, G., “Thomas Kuhn: The Road Since *Structure*,” pp. 574-575.

³² KUHN, TH. S., “The Road Since *Structure*,” in KUHN, TH. S., *The Road Since Structure*, p. 93.

³³ See note 23 on his book *Word and Object*.

³⁴ KUHN, TH. S., “The Road Since *Structure*,” p. 93.

³⁵ The characterization of “local incommensurability” appears in KUHN, TH. S., “Commensurability, Comparability, Communicability,” in KUHN, TH. S., *The Road Since Structure*, pp. 35-37.

³⁶ “It is needed (...) to defend notions like truth and knowledge from, for example, the excesses of postmodernist movements like the strong program,” KUHN, TH. S., “The Road Since *Structure*,” p. 91.

³⁷ KUHN, TH. S., “The Road Since *Structure*,” p. 91.

³⁸ KUHN, TH. S., “What are Scientific Revolutions?,” in KRÜGER, L., DASTON, L. J., and HEIDELBERGER, M. (eds.), *The Probabilistic Revolution. Vol. 1: Ideas in History*, The MIT Press, Cambridge, MA, 1987, pp. 7-22; reprinted in KUHN, TH. S., *The Road Since Structure*, pp. 13-32.

scientific knowledge already possessed and where change increases in a cumulative way to what has been done before. Meanwhile, the second possibility is a non-cumulative one. Thus, “they involve discoveries that cannot be accommodated within the concepts in use before they were made.”³⁹ He links here revolutionary change and conceptual innovation that does not fit into the preceding framework. Again, the emphasis goes to the language: “violation or distortion of a previously unproblematic scientific language is the touchstone for revolutionary change.”⁴⁰

Now Kuhn highlights three features as characteristic of *scientific revolutions*. (i) Revolutionary changes are — in one way or another — holistic: there cannot be piecemeal as is the case in normal changes or cumulative ones. Thus, in the revolutionary change there are two options: either to live with incoherence or to revise a number of interrelated generalizations together.⁴¹ (ii) There is a change in the language that “alters not only the criteria by which terms attach to nature but also, massively, the set of objects or situations to which those terms attach.”⁴² (iii) Revolutions come along with changes in the taxonomic categories. This change involves an adjustment of the relevant criteria for the categorization but it also includes a variation “of the way in which given objects and situations are distributed among preexisting categories.”⁴³ This redistribution affects more than one category and, because they are interdefined, the modification is holistic (i.e., it impinges in the whole set of categories).

Taking into account this intellectual trajectory — Kuhn’s three philosophical-methodological periods —, the interesting thing is that he considers his own view as a “post-Darwinian Kantianism.”⁴⁴ This label in this third stage might be understandable from two angles. On the one hand, there is similarity between Kantian categories and Kuhnian lexicons, insofar as both cases — categories and lexicons — give the *preconditions* of any possible experience.⁴⁵ And, on the other hand, the post-Darwinian trait is in Kuhn to the extent that his lexicons are evolutionary, which is not the case in Kant’s categories. Moreover, Kuhnian lexicons have historicity and social character: they change as time passes by and when they move from one community to another.⁴⁶ Kuhn’s final outcome is then a Kantian approach oriented towards language and with mobile categories (in principle, both historical and social ones). This distinguishes his view from the original Kantian framework, where the primacy is in a timeless cognitive structure that has general validity.

³⁹ KUHN, TH. S., “What are Scientific Revolutions?,” in KUHN, TH. S., *The Road Since Structure*, p. 14.

⁴⁰ KUHN, TH. S., “What are Scientific Revolutions?,” p. 32.

⁴¹ Cf. “What are Scientific Revolutions?,” p. 29.

⁴² KUHN, TH. S., “What are Scientific Revolutions?,” pp. 29-30.

⁴³ “What are Scientific Revolutions?,” p. 30.

⁴⁴ “The position I’m developing is a sort of post-Darwinian Kantianism. Like the Kantian categories, the lexicon supplies preconditions of possible experience. But lexical categories, unlike their Kantian forebears, can and do change, both with time and the passage from one community to another,” KUHN, TH. S., “The Road Since Structure,” p. 104.

⁴⁵ This brings an unexpected parallelism with Hans Georg Gadamer’s hermeneutics, because — for him — language is a precondition of scientific experience. Cf. GADAMER, H. G., *Wahrheit und Methode*, J. C. B. Mohr (P. Siebeck), Tubinga, 5th ed., 1986 (1st ed., 1960), pp. 452-454 and 478. On the role of language regarding scientific experience in this thinker, see MARTINEZ, J. M., *La Filosofía de las Ciencias Humanas y Sociales de H. G. Gadamer*, P. P. U., Barcelona, 1994; especially, pp. 155-157, 272-273 and 375.

⁴⁶ *Sensu stricto*, evolutionism based on Charles Darwin and historicity — understood in a strict sense — are not the same. On the notion of “historicity,” cf. GONZALEZ, W. J., “Caracterización del objeto de la Ciencia de la Historia y bases de su configuración metodológica,” in GONZALEZ, W. J. (ed.), *Acción e Historia. El objeto de la Historia y la Teoría de la Acción*, Publicaciones Universidad de A Coruña, A Coruña, 1996, pp. 25-111.

1.2. Thagard's Conceptual Revolutions

An alternative to Kuhn's scientific revolutions came with the book *Conceptual Revolutions*, written by Paul Thagard.⁴⁷ In his approach, a conceptual change is revolutionary if it involves the replacement of a whole system of concepts and rules by a new system.⁴⁸ He presents a theory of conceptual revolutions in an attempt to illuminate such cases: the development of Copernicus' theory of the solar system, Newtonian mechanics, Lavoisier's oxygen theory, Darwin's theory of evolution, Einstein's theory of relativity, quantum mechanics, and the geological theory of plate tectonics. Thagard focuses the attention on central points and he avoids duplicating the excellent narratives that historians of science have provided. The emphasis is then on furnishing a new cognitive perspective on scientific revolutions.

Certainly Thagard's "conceptual revolutions" differ from Kuhn's "scientific revolutions" in several ways. The main differences lie in the rationality of the conceptual change and in the commensurability of theories. Both aspects are defended in the book within the theory of explanatory coherence, which criticizes the impediments to rationality in science and reaffirms the comparability of theories. *De facto*, Thagard accepts objective elements in the interpretation of revolutions. This distances him from the Kuhnian conversion, the primacy of the sociological explanation regarding the revolutionary change, and the linguistic emphasis to understand scientific revolutions in terms of translation.⁴⁹

Following these lines, Thagard rejects Kuhnian positions such as the purely subjective explanation of conceptual change, the relativistic option of sociological kind and the interpretation of conceptual change as mere "translation" of languages.⁵⁰ For him, the overall picture should be questioned while keeping the core idea of revolutions in science: "Kuhn's general view of scientific revolutions and his accounts of particular scientific episodes must be questioned, but his basic claim that the development of scientific knowledge includes revolutionary changes can be sustained."⁵¹

Basically, the book might be divided into four parts. Firstly, there is a presentation of the problem of revolutionary conceptual change, which requires attention to Kuhn as starting point (chapter 1). Secondly, Thagard offers a theoretical approach, which includes the study of concepts and conceptual systems, conceptual change, the theory of explanatory coherence and the links between dynamics, rationality and explanation (chapters 2-5). Thirdly, there are several historical analyses of the revolutions in science: the cases of chemistry, biology, geology and physics as well as the possible revolution in psychology (chapters 3-9). Fourthly, there is the comparison between conceptual change in scientists and children (chapter 10). To some extent, the second and third parts overlap, because the theoretical approach is usually linked to the presentation of the chemical revolution.

⁴⁷ On this book see GONZALEZ, W. J., "P. Thagard: Conceptual Revolutions," *Mind*, v. 104, n. 416, (1995), pp. 916-919; and GONZALEZ, W. J., "Towards a New Framework for Revolutions in Science," *Studies in History and Philosophy of Science*, v. 27, n. 4, (1996), pp. 607-625. Both are used to develop the present analysis.

⁴⁸ THAGARD, P., *Conceptual Revolutions*, p. 6.

⁴⁹ The linguistic focus is in his third philosophical-methodological period: KUHN, TH. S., "Commensurability, Comparability, Communicability," in ASQUITH, P. D. and NICKLES, TH. (eds.), *Proceedings of the 1982 Biennial Meeting of the Philosophy of Science Association*, vol. 2, pp. 669-688.

⁵⁰ Cf. THAGARD, P., *Conceptual Revolutions*, pp. 109-117.

⁵¹ THAGARD, P., *Conceptual Revolutions*, p. 4.

Conceptual Revolutions continues the line of thought of his earlier *Computational Philosophy of Science*:⁵² a combination of philosophy, artificial intelligence and cognitive psychology. Thagard considers the dynamic aspect of discovery and evaluation of theories in scientific revolutions. He offers a theory of explanatory coherence,⁵³ which is accompanied by a computational model of theory evaluation. The viewpoint belongs to the internal philosophy of science — the conceptual change is inside the scientific theories — rather than the external orientation (the social contribution to the development of theories). But his conception of revolutionary conceptual change includes several elements of psychology of invention as well as influences of sociological factors.

Through the study of *theory dynamics, rationality, and explanation* Thagard completes his theoretical approach to conceptual revolutions. His key points on these issues are very clear. (i) Scientific changes differ in the extent to which new theories incorporate old ones. Moreover, they are not cumulative, since new theories involve the rejection of some theoretical claims of the theories they replace. (ii) There is sufficient continuity in scientific revolutions to justify the claim that adoption of new theories is in general rational. (iii) Explanation has many strands: deductive, statistical, schematic, analogical, causal, and linguistic.⁵⁴ In the light of these claims, scientific revolutions can be understood as rational changes, where the mechanisms of change are internal to science. In other words, science is self-corrective.⁵⁵

Thus, Thagard makes positive contributions to the problem of conceptual revolutions, insofar as he introduces the theory dynamics in terms of *transition* from one theory to another, accepts rationality in the scientific revolutions and tries to develop a cognitive model of explanation. In effect, his account of the dynamic relation of scientific theories adopts a position on replacement of theories which avoids mere incorporation — the assumption that new theories must be consistent with established science — and criticizes the account of theory replacement in terms of Kuhn's thesis of incommensurability between successive theories.⁵⁶

Accordingly, *rationality* is defended by Thagard as an element of revolutions in science: a) the Kuhnian psychological account of conversion shows that it has little in common with scientific change; b) it is easy to see the limitations of the models of sociologists of science when they explain the development of science without treatment of rationality; c) Kuhn's analogy — in his third period — between conceptual systems in science and translation of language is limited.⁵⁷ By means of the cognitive model of explanation, Thagard seeks to capture some relevant aspects of explanation in science and everyday life.⁵⁸ His position is understood as a part of a theory of cognitive architecture, following the line initially opened by the “general problem solver” of Allen Newell and Herbert Simon⁵⁹ and later on transformed into “cognitive architecture” by John R. Anderson⁶⁰.

⁵² THAGARD, P., *Computational Philosophy of Science*, The MIT Press, Cambridge, MA, 1988.

⁵³ This theory of explanatory coherence, which is intended to account for a wide range of explanatory inferences, is implemented in a connectionist computer program called “ECHO,” cf. THAGARD, P., *Conceptual Revolutions*, p. 71.

⁵⁴ Cf. THAGARD, P., *Conceptual Revolutions*, p. 130.

⁵⁵ Cf. GONZALEZ, W. J., “Towards a New Framework for Revolutions in Science,” p. 613.

⁵⁶ Cf. THAGARD, P., *Conceptual Revolutions*, pp. 104-107.

⁵⁷ Cf. *Conceptual Revolutions*, pp. 103 and 108-117.

⁵⁸ Cf. THAGARD, P., *Conceptual Revolutions*, p. 127.

⁵⁹ Cf. NEWELL, A. and SIMON, H. A., *Human Problem Solving*, Prentice Hall, Englewood Cliffs, NJ, 1972.

⁶⁰ Cf. ANDERSON, J. R., *The Architecture of Cognition*, Harvard University Press, Cambridge, MA, 1983.

For Thagard, *theory replacement* takes four possible forms, which makes the relations between successive theories richer than Kuhn's normal and revolutionary changes. In effect, according to *Conceptual Revolutions*, "at the most general level, we can distinguish four kinds of relations between successive theories, ordered by decreasing amounts of cumulateness: incorporation, sublation, supplantation, and disregard."⁶¹ In comparison with Kuhn's views, Thagard insists that the aim of an objective notion of "explanation" is very important. He recognizes that the theory of explanatory coherence depends on the existence of an *objective notion* of explanation.⁶²

Concerning the historical analyses of *revolutions in science*, Thagard relies on the study of the chemical revolution, which was the topic of a previous paper.⁶³ From this case he draws the strongest arguments for his theoretical approach,⁶⁴ where his examples are taken from the *chemical revolution*: the conceptual change from Georg E. Stahl's phlogiston theory to Antoine-Laurent Lavoisier's theory of oxygen. After the study of the chemical revolution, he analyses several further revolutions: Darwinian, geological, in physics, and the possible revolution in psychology.

Darwinian revolution, seeing it both in a historical context and from a philosophical point of view, has been discussed specifically elsewhere.⁶⁵ In this regard, the alternative built up by Charles Darwin against the biological fixism and the time he spent in setting up his own position could be presented as a very illustrative case of conceptual revolution. In my judgment, the reconstruction of his intellectual itinerary and the interrelation with other contributions of his time, can teach us several things for a general perspective on conceptual revolutions. They are related to innovation, time of maturation, justification of the new concepts and adequacy to the reality.⁶⁶

Besides the revolutions in chemistry and biology, Thagard pays attention to the geological and physical revolutions.⁶⁷ The study of the *geological revolution* appears as one of the novelties of the book. This case, which he studied in papers published jointly with Gregory Nowak,⁶⁸ and the chemical revolution are analyzed in greater depth than the others. Thagard considers that there are some cognitive mechanisms, such as abduction and conceptual combination, that contributed to the discovery of the continental drift, which is the forerunner of the theory of plate tectonics. The new theory required new concepts, such as "seafloor spreading," and a

⁶¹ THAGARD, P., *Conceptual Revolutions*, p. 105; cf. *Conceptual Revolutions*, p. 250.

⁶² Cf. *Conceptual Revolutions*, p. 118. According to the theory of explanatory coherence (TEC), a new theory will replace an old one if its hypotheses possess greater explanatory coherence. But Thagard points out that TEC is still too vague to show how this could work (*Conceptual Revolutions*, p. 69). This feature of the recognition of the internal limitations of his proposals also appears on other occasions (*Conceptual Revolutions*, pp. 103, 113, 156, 160, 216, 252, and 263).

⁶³ Cf. THAGARD, P., "The Conceptual Structure of the Chemical Revolution," *Philosophy of Science*, v. 57, (1990), pp. 183-209.

⁶⁴ See THAGARD, P., *Conceptual Revolutions*, chs. 2, 3, 4 and 5.

⁶⁵ Cf. GONZALEZ, W. J., "Evolutionism from a Contemporary Viewpoint: The Philosophical-Methodological Approach," in GONZALEZ, W. J. (ed.), *Evolutionism: Present Approaches*, Netbiblo, A Coruña, 2008, pp. 3-59; especially, section 1.3, pp. 13-21.

⁶⁶ Cf. GONZALEZ, W. J., "Evolutionism from a Contemporary Viewpoint: The Philosophical-Methodological Approach," pp. 19-20.

⁶⁷ These revolutions are discussed respectively in chapters 6, 7 and 8 of *Conceptual Revolutions*.

⁶⁸ Cf. THAGARD, P. and NOWAK, G., "The Conceptual Structure of the Geological Revolution," in SHRAGER, J. and LANGLEY, P. W. (eds.), *Computational Models of Scientific Discovery and Theory Formation*, Morgan Kaufmann, San Mateo, 1990, pp. 27-72.

conceptualization of continents and ocean floors as different kinds of surfaces and parts of plates, instead of as parts of the Earth crust.⁶⁹

Revolutions in physics are, for Thagard, four: Copernicus' astronomical theory; Newton's classical mechanics; Einstein's theory of relativity; and quantum mechanics. All of them involved substantial change in kind relations, and the latter includes radical change in part relations as well.⁷⁰ The book summarizes in a very accessible way these "classical" examples of revolutions, adding the interpretation from his theory of explanatory coherence. Thus, Copernicus supplanted Ptolemaic astronomy; Newton completed the demise of Aristotelian physics and supplanted Descartes' vortex theory of gravity; relativity and quantum theories showed the inapplicability of Newtonian theory to objects that are very massive, extremely small or with a high velocity. These last cases of physics have a more cumulative character than the other scientific revolutions.⁷¹

Under the title *Revolutions in Psychology?* Thagard studies in the book his only example from the social sciences.⁷² Until then, he had analyzed several revolutions in the natural sciences (chemistry, biology, geology, physics).⁷³ In all of them, he considers that the acceptance of the new theories is due to their greater explanatory coherence than the old theories. Regarding the social sciences, he highlights that they have not been yet developed to the point where they have a coherent unifying theory to be overthrown.⁷⁴ This is, for him, the first step for the study of revolutions in psychology. Behaviourism and cognitivism are his cases seen as "revolutions." However, in his vision, both are better described as competing *approaches* than as competing explanatory *theories*.⁷⁵ These approaches — behaviourist and cognitivist — involved abundant conceptual change, but he considers that their rise depends more on estimates of future explanatory coherence than on evaluation of the explanatory coherence of specific theories.⁷⁶

After the recognition that there are only *quasi-revolutions* in psychology, Thagard reviews the results leading to scientific revolutions. He sees different kinds of discovery processing operating: a) data-driven (generalized from observations and experiments); b) explanation-driven (abductive); and c) coherence-driven (formed to overcome contradictions). The explanatory relations between the old and new theories follow four possibilities: 1) *incorporation*, when the old theory is merely absorbed into the new one; 2) *sublation*, in which rejection and reorganization of concepts takes place even though the explanatory hypotheses and successes of the old theory

⁶⁹ Cf. THAGARD, P., *Conceptual Revolutions*, p. 182.

⁷⁰ Cf. *Conceptual Revolutions*, p. 191.

⁷¹ Cf. THAGARD, P., *Conceptual Revolutions*, p. 224.

⁷² See *Conceptual Revolutions*, ch. 9, pp. 225-245.

⁷³ Later on he has also studied formal sciences from the point of view of conceptual change: cf. RUSNOCK, P. and THAGARD, P., "Strategies for Conceptual Change: Ratio and Proportion in Classical Greek Mathematics," *Studies in History and Philosophy of Science*, v. 26, (1995), pp. 107-131.

⁷⁴ Cf. *Conceptual Revolutions*, p. 225.

⁷⁵ Cf. THAGARD, P., *Conceptual Revolutions*, p. 225. Thagard distinguishes "approach," "framework" and "theory." Thus, a single approach could have various frameworks for investigating the phenomena; frameworks (e.g., Pavlovian conditioning) are more specific than approaches and are vaguer than theories; a theory has identifiable hypotheses and ranges of explanation: it includes conceptual relations and past problem-solving successes in addition to hypotheses (*Conceptual Revolutions*, p. 226).

⁷⁶ Cf. THAGARD, P., *Conceptual Revolutions*, p. 245.

are absorbed into the new theory; 3) *supplantation*, when the old theory is summarily rejected; and 4) *disregard*, in which no attention is paid by proponents of new theory to the old theory.⁷⁷

Subsequently, the final chapter is devoted to the comparison between conceptual change in scientists and children, which constitutes the fourth part of the book.⁷⁸ Thagard uses the label “explanationist” for his own view, which he distinguishes from empiricism and rationalism whilst not opposing them outright. For him, the “explanationist” seeks to combine the most plausible aspects of empiricism and rationalism.⁷⁹ From this viewpoint, he compares *conceptual change in scientists and children*, according to the degree of conceptual changes: additions; deletions; simple reorganizations; revisionary reorganizations; and hierarchies interpretations.⁸⁰ His conclusion is certainly cautious: “from research to date, conceptual development in children appears to be less revolutionary than occurs in science... Whether explanatory coherence plays a role in theory development in children is an open question.”⁸¹

1.3. Towards New Aspects

Almost fifty years since the publication of *The Structure of Scientific Revolutions* and nearly twenty years since the book *Conceptual Revolutions* was released, new aspects need to be discussed. In my judgment, the state of the art is not the same as two decades ago. Generally speaking, when a comparison of both books is made, Thagard’s book paints a better picture of “revolutions” in science than Kuhn’s proposals.⁸²

It seems to me that the improvement can be recognized in several factors: (i) between the previous scientific theory and the new one there is always the element of rationality even when shift is radical; (ii) the changes might include some aspects of conceptual continuity and overlapping within a new focus; (iii) commensurability of scientific theories is possible even in cases of “supplantation” (in which the old theory is summarily rejected), because a common conceptual ground could be obtained for a comparison; and (iv) the theory of scientific explanation should be based on objective grounds.⁸³ I consider that the actual history of science matches better with this view of conceptual revolutions than with Kuhnian scientific revolutions, especially when compared with his views of the initial period.

Since 1992, the year of the publication of *Conceptual Revolutions*, there have been a set of new aspects on conceptual change based on a cognitive approach. Two of them are connected with the subtitle of the present book — *From Cognitive Science to Medicine* — which makes explicit new areas of philosophical interest developed from a cognitive stance. On the one hand, there has been an enlargement of cognitive sciences during these years, especially towards neuroscience; and, on the other, there is also a clear interest in discussing problems raised by medicine (as a science and some kind of diseases), which includes analyses made from a cognitive

⁷⁷ Cf. *Conceptual Revolutions*, p. 250.

⁷⁸ See *Conceptual Revolutions*, ch. 10, pp. 246-263.

⁷⁹ Cf. THAGARD, P., *Conceptual Revolutions*, p. 251.

⁸⁰ Cf. *Conceptual Revolutions*, p. 252.

⁸¹ Cf. THAGARD, P., *Conceptual Revolutions*, p. 263.

⁸² Nevertheless, Thagard’s views on that book require some revisions, cf. GONZALEZ, W. J., “Towards a New Framework for Revolutions in Science,” pp. 623-625. In this regard, see also the next chapter of the present volume, pp. 39-62.

⁸³ Cf. GONZALEZ, W. J., “P. Thagard: Conceptual Revolutions,” p. 919. Cf. GONZALEZ, W. J. (ed.), *Diversidad de la explicación científica*, Ariel, Barcelona, 2002.

perspective.⁸⁴ Thus, among the new philosophical-methodological focuses on medicine, there are some that emphasize conceptual changes, mainly those due to the way of making discoveries or the forms of testing them.

Firstly, there is an enlargement of cognitive sciences towards neuroscience, which is emphasized at present by Thagard. It is noticeable in the chapter “Conceptual Change in Cognitive Science: The Brain Revolution.”⁸⁵ But the move towards neuroscientific support for concepts is broader than the study of the knowledge itself as based on the brain. Besides the cognitive sciences, the contents of neuroscience have also consequences in other scientific fields, such as economics. Moreover, there is nowadays a new branch of this traditional science: neuroeconomics.⁸⁶ This epistemological and methodological novelty is relevant: it means that economics, which is a science of the artificial as well as a social science, is now open to the use of approaches characteristic of natural sciences (mainly on observation and experimentation).⁸⁷

Secondly, there is the important aspect of the increasing interest in medicine, in general, and in some kind of diseases, in particular. On the one hand, the philosophical-methodological analysis of medicine as a science has increased considerably in recent decades. Thus, there are new reflections that have drawn attention to aspects that previously went almost unnoticed, such as the possible demarcation with “alternative medicine”⁸⁸ or the methodological problems on clinical trials and the use of randomization.⁸⁹ But, on the other hand, there are new analyses of medicine based on the conceptions of thinkers in favor of revolutions in science, such as Kuhn,⁹⁰ and novel studies on diseases made with the enlarged criteria of cognitive science, mainly those of the neuroscientist vision of human knowledge. This is the case of Thagard’s

⁸⁴ See for example the book THAGARD, P. (ed.), *Philosophy of Psychology and Cognitive Science*, Elsevier, Amsterdam, 2007. It includes three chapters directly devoted to these topics: HARDCASTLE, V. G., “The Theoretical and Methodological Foundations of Cognitive Neuroscience,” pp. 295-311; ELIASMITH, CH., “Computational Neuroscience,” pp. 313-338; and GRAHAM, G. and LYNN STEPHENS, G., “Psychopathology: Minding Mental Illness,” pp. 339-367.

⁸⁵ THAGARD, P., “Conceptual Change in Cognitive Science: The Brain Revolution,” in GONZALEZ, W. J. (ed.), *Conceptual Revolutions: From Cognitive Science to Medicine*, Netbiblo, A Coruña, 2011, pp. 65-78.

⁸⁶ Cf. McCABE, K. A., “Neuroeconomics and the Economic Sciences,” *Economics and Philosophy*, v. 24, n. 3, (2008), pp. 345-368; and HARRISON, G. W., “Neuroeconomics: A Critical Reconsideration,” *Economics and Philosophy*, v. 24, n. 3, (2008), pp. 303-344.

⁸⁷ The new study of human decision-making combines procedures based on natural sciences (the neuronal research) and the processes of a social science — economics —, which is also a science of the artificial in the case of the rationality of the decision-making. Cf. GONZALEZ, W. J., “Recent Approaches on Observation and Experimentation: A Philosophical-Methodological Viewpoint,” in GONZALEZ, W. J. (ed.), *New Methodological Perspectives on Observation and Experimentation in Science*, Netbiblo, A Coruña, 2010, pp. 9-48; especially, pp. 19-20, 30 and 32.

⁸⁸ Cf. GILLIES, D. A., “El problema de la demarcación y la Medicina alternativa,” in GONZALEZ, W. J. (ed.), *Karl Popper: Revisión de su legado*, Unión Editorial, Madrid, 2004, pp. 197-219. See also THAGARD, P. and ZHU, J., “Acupuncture, Incommensurability, and Conceptual Change,” in SINATRA, G. M. and PINTRICH, P. R. (eds.), *Intentional Conceptual Change*, Erlbaum, Mahwah, NJ, 2003, pp. 79-102.

⁸⁹ Cf. WORRALL, J., “Why Randomize? Evidence and Ethics in Clinical Trials,” in GONZALEZ, W. J. and ALCOLEA, J. (eds.), *Contemporary Perspectives in Philosophy and Methodology of Science*, Netbiblo, A Coruña, 2006, pp. 65-82; and WORRALL, J., “Why There’s No Cause to Randomize,” *The British Journal for the Philosophy of Science*, v. 58, n. 3, (2007), pp. 451-488.

⁹⁰ An excellent example of the analysis in medicine of Kuhnian approaches is in GILLIES, D. A., “Kuhn on Discovery and the Case of Penicillin,” in GONZALEZ, W. J. and ALCOLEA, J. (eds.), *Contemporary Perspectives in Philosophy and Methodology of Science*, pp. 47-63.

chapter on “Conceptual Change in Medicine: Explaining Mental Illness,”⁹¹ which gives some new philosophical perspectives in a field already worked by him.⁹²

Both new aspects — the enlargement of the cognitive approach through neuroscience and the direct discussion on philosophical problems related to medicine — are analyzed in this book from different angles. In addition, there is also an analysis of key issues related to the problem of conceptual revolutions at the present stage. Some of them can be found in the chapter “Conceptual Changes and Scientific Diversity: The Role of Historicity.”⁹³ There the focus is on the characterization of *concepts* and emphasis is put on *historicity* as crucial for grasping conceptual changes in science that lead to diversity. These central elements on scientific concepts as marked by historicity have commonly been underestimated — or, at least, have not received enough attention — in the cognitive approach.⁹⁴

Even though there are some insights in certain authors of the “cognitive turn” regarding conceptual changes in *historical terms*, such as Thomas Nickles⁹⁵ and Nancy J. Nersessian,⁹⁶ more work needs to be done. This is one of the reasons why the bibliography of this chapter has been articulated in three steps: 1) Scientific Change: Historicity, Evolution, and Revolution; 2) On Revolutions in Science; and 3) Conceptual Change and Conceptual Revolution. These references initially draw attention to the general framework of the scientific change, which might be seen in terms of historicity, evolution, and revolution. This triadic platform is useful for understanding the specific analysis of revolutions in science. It also underlies the posterior perspective of “conceptual change” conceived as the broader basis for the “conceptual revolution.”

2. ORIGIN AND CHARACTERISTICS OF THE PRESENT BOOK

Originally these papers were presented at the “Conference on Conceptual Revolutions: From Cognitive Sciences to Medicine” (*Jornadas sobre Revoluciones conceptuales: De las Ciencias Cognitivas a la Medicina*). This activity was organized by the University of A Coruña and the Society of Logic, Methodology and Philosophy of Science in Spain. The aim of the conference was the conceptual revolutions as axis of scientific change. In this regard, the initial interest was twofold: (i) the cognitive sciences and its characterization of “concepts,” and (ii) a direct analysis of medicine as a science where scientific changes have been most noticeable in recent

⁹¹ THAGARD, P., “Conceptual Change in Medicine: Explaining Mental Illness,” in GONZALEZ, W. J. (ed.), *Conceptual Revolutions: From Cognitive Science to Medicine*, pp. 157-177.

⁹² On medicine he has a well-known book: THAGARD, P., *How Scientists Explain Disease*, Princeton University Press, Princeton, 1999. His previous publications on that area, which were used to writing it, are pointed out in pages xvii-xviii.

⁹³ Cf. GONZALEZ, W. J., “Conceptual Changes and Scientific Diversity: The Role of Historicity,” in GONZALEZ, W. J. (ed.), *Conceptual Revolutions: From Cognitive Science to Medicine*, pp. 39-62.

⁹⁴ This seems to be recognized in some cases, see for example NERSESSIAN, N. J., “Opening the Black Box: Cognitive Science and History of Science,” *Osiris*, v. 10, (1995), pp. 194-211.

⁹⁵ Cf. NICKLES, TH., “Kuhn, Historical Philosophical of Science, and Case-Based Reasoning,” *Configurations*, v. 6, (1998), pp. 51-85; NICKLES, TH., “Normal Science: From Logic to Case-Based and Model-Based Reasoning,” in NICKLES, TH. (ed.), *Thomas Kuhn*, Cambridge University Press, Cambridge, 2003, pp. 142-177; and NICKLES, TH., “Disruptive Scientific Change,” in SOLER, L., SANKEY, H. and HOYNINGEN-HUENE, P. (eds.), *Rethinking Scientific Change and Theory Comparison: Stabilities, Ruptures, Incommensurabilities?*, Springer, Dordrecht, 2008, pp. 351-379.

⁹⁶ Cf. NERSESSIAN, N. J., “Kuhn and the Cognitive Revolution,” *Configurations*, v. 6, (1998), pp. 87-120; NERSESSIAN, N. J., “Conceptual Change and Commensurability,” in SANKEY, H. and P. HOYNINGEN-HUENE, P. (eds.), *Incommensurability and Related Matters*, Kluwer, Dordrecht, 2001, pp. 275-301; and NERSESSIAN, N. J., “Kuhn, Conceptual Change, and Cognitive Science,” in NICKLES, TH. (ed.), *Thomas Kuhn*, pp. 178-211.

times. This explains the focus on neuroscience in connection with concepts, but also the study of neurodegenerative diseases.

Concerning these aspects of philosophical-methodological analysis of the neuroscientific approach to concepts and some central medical problems, Paul Thagard is an influential figure. He is Professor of Philosophy at the University of Waterloo (Canada) as well as Director of the program of Cognitive Science. In 2007 he received a national award of research — the Molson Prize — given by the Canada Council for the Arts. Besides the volume *Conceptual Revolutions*, he is the author of another well-known book: *How Scientists explain Disease*, which focuses on medicine as a science. Nowadays he researches neuroscience and his two papers here deal with that discipline, mainly from epistemological and methodological perspectives.

Thagard's background includes a dissertation in philosophy at the University of Toronto and a Masters degree in computer sciences at the University of Michigan. He has been president of the Society for Machines and Mentality (1997-1998) and director of the Governing Board of the Cognitive Science Society, 1998-1999. In 1999 he was elected Fellow of the Royal Society of Canada. In 2003 he received the University of Waterloo Award for Excellence in Research, and in 2005 he was appointed Professor of Research there. In 2006 he became Associate Editor of the journal *Cognitive Science* and he was elected Fellow of the Cognitive Science Society.

Among Thagard's books are *Computational Philosophy of Science* (The MIT Press, 1988); *Mind: Introduction to the Cognitive Science* (The MIT Press, 1996; 2nd ed., 2005); *Coherence in Thought and Action* (The MIT Press, 2000); and *Hot Thought: Mechanisms and Applications of Emotional Cognition* (The MIT Press, 2006). He is co-author of *Mental Leaps: Analogy in Creative Thought* (The MIT Press, 1995) and *Induction: Processes of Inference, Learning, and Discovery* (The MIT Press, 1986). He is also the editor of the book *Philosophy of Psychology and Cognitive Science* (Elsevier, 2007).

Besides Thagard, the conference included invited speakers such as Matti Sintonen. He is Professor of Theoretical Philosophy at the University of Helsinki, where he is the assistant director of the Department of Philosophy. He gained the position of Professor of Philosophy of Science at the University of Tampere. He taught philosophy of social sciences at the University of Helsinki. Sintonen is a permanent member of Clare Hall at the University of Cambridge. In addition, he is a member of the Finnish Academy of Sciences and Letters. He was the first president of the European Philosophy of Science Association (EPSA).

Sintonen's research has been focused on philosophy of science, with special interest in philosophy of biology and philosophy of the social sciences. He is the author of influential papers such as "Realism and Understanding" (1982) and "Basic and Applied Sciences — Can the Distinction (Still) Be Drawn?" (1990). He wrote the book *The Pragmatics of Scientific Explanation* (1984). He is the co-editor of the volume *Realism in Action: Essays in the Philosophy of Social Sciences* (2003).

Both authors — Thagard and Sintonen —, in addition to the other guest speakers (Pascual Martínez Freire, José María Martínez Selva, and Javier Romero) and the authors of the contributed papers, presented their papers on 5-6 March 2009. The scientific committee was formed by Wenceslao J. Gonzalez (Professor of Logic and Philosophy of Science at the University of A Coruña), Javier Echeverría (Professor of Logic and Philosophy of Science at the University of Basque Country, and he has been Professor of Science, Technology and Society at the Higher

Superior Council of Scientific Research), Juan Arana (Professor of Philosophy at the University of Seville) and Pascual Martínez Freire (Professor of Logic and Philosophy of Science at the University of Malaga).

All were central elements of the “XIV Conference on Contemporary Philosophy and Methodology of Science” (*XIV Jornadas sobre Filosofía y Metodología actual de la Ciencia*). This activity received the support of Ferrol City Hall. The mayor present at the opening ceremony and the councilwoman for culture attended the closure. The University of A Coruña received the backing of *Santander* bank to promote this conference as well as other activities through the Vice-Rectorate’s office for Culture.

Regarding persons, I want to mention the Rector of the University of A Coruña, for his manifest consideration of these *Jornadas*, and the Vice-Rector of the Ferrol Campus, who has given support to this congress. My appreciation goes expressly to Paul Thagard for accepting my invitation, which has allowed us to go more deeply into the issues on conceptual revolutions. My recognition also goes to Matti Sintonen, who is a very well known figure in the European philosophy of science. I am grateful for the presence of my colleagues Pascual Martínez Freire, José María Martínez Selva, and Javier Romero. In addition, I am very happy with the authors of the contributed papers.

Within the closer sphere of collaborators, I thank the work done by the people of the support team. They have been especially helpful in material and organizational matters. In this regard, my gratitude is greater in the case of those persons that have been collaborating in all the editions of these *Jornadas*. Furthermore, I am thankful to those who have assisted me in administrative matters. In addition, I am grateful to the media for informing about this activity. Obviously, my warm recognition to those who have cooperated in editorial tasks: José Fco. Martínez Solano, Amanda Guillán and, especially, Jessica Rey.

3. BIBLIOGRAPHY ABOUT CONCEPTUAL REVOLUTIONS

There is a large amount of bibliographical information on “the scientific revolution” understood as the key scientific change that originated modern science.⁹⁷ Although the list of references is considerable in those cases, little attention is commonly paid to the *conceptual revolution* introduced when we were moving ahead “on the shoulders of giants.” In the present bibliographical section, although there are references to that historical period, the focus of interest is different. It is oriented towards papers and books devoted to changes in science due to three main possibilities: a) the introduction of new concepts, b) the noticeable modification of those already available, and c) the emphasis on novel aspects of the existing concepts. They have been seen within three main frames: historicity, evolution, and revolution.

Another approach on radical changes is the Kuhnian’s characterization of “scientific revolutions.” Its interest is clear for conceptual revolutions insofar as in Kuhn’s analysis the “internal” component of science has more epistemological weight than the contextual aspects of scientific activity. The specific bibliography of Kuhn’s works and a substantial amount of publications about his successive conceptions of *scientific revolutions* can be found in GONZALEZ, W. J., “Las revoluciones científicas y la evolución de Thomas S. Kuhn,” in

⁹⁷ See, for example, HATCH, R. A., “The Scientific Revolution: Classic and Historiographic Sources,” <http://www.clas.ufl.edu/users/ufhatch/pages/03-sci-rev/sci-rev-teaching/bibliography/05bibl-sr-shrt.htm> (access on 16.I.2011).

GONZALEZ, W. J. (ed.), *Análisis de Thomas Kuhn: Las revoluciones científicas*, Trotta, Madrid, 2004, pp. 15-103; especially, pp. 80-103. Nevertheless, due to his enormous impact, there is here a selection of his works related to scientific revolutions as well as very influential analyses of his thought in this regard.

Underlying the problem of revolutions in science — especially as conceptual modifications —, there is a previous step: the existence of *scientific change* and the recognition of different forms of interpreting it. From 1960s to date, the stress on changes in science was more intense during the “historical turn” (Kuhn, Lakatos, etc.). But the analysis of scientific changes was quite different: the initial Kuhnian conceptual relativism was criticized by the Lakatosian combination of objectivity and historicity in scientific concepts. Meanwhile, in 1960s and 1970s, there were also views with a distinct perspective regarding internal changes in science, such as the conceptions around the “evolutionary epistemology.” In addition, between 1975 and 1985 the scientific change was connected to the issue of the scientific progress.⁹⁸

Thereafter, the “naturalist return” supported different versions of evolutionary approaches for the advancement of science, where Philip Kitcher has made important contributions. Some of the naturalist considerations of scientific discoveries have been developed in combination with cognitive views on science. At the same time, there have also been orientations directly based on cognitive sciences, such as those in favor of the existence of conceptual revolutions in science, which in the case of Thagard was of a naturalist kind as well (an epistemological, methodological, ontological and axiological naturalism).⁹⁹

Consequently, this bibliographical section on conceptual revolutions takes into account all these historical events of the philosophy and methodology of science of the second half of the twentieth century and the first decade of the twenty-first. Accordingly, it starts with the scientific change in general seen mainly from three viewpoints. Then follows the direct reflection on revolutions in science, where Kuhnian schemes have been very influential. Finally, the bibliography deals with the core of this volume: conceptual change and conceptual revolution. The bibliographic information seeks to display relevant contributions in the three steps and, obviously, it is a selection of references instead of an exhaustive list of the publications available.

3.1. Scientific Change: Historicity, Evolution, and Revolution

Structure and dynamics have been central aspects in science and in the philosophical-methodological reflection on this human activity. Scientific change is the core of the dynamics in science, both basic and applied. Among the interpretations of scientific change are those that emphasize *historicity*, which involves an intrinsic variability of science as a human undertaking, those that focus on a form of *evolution*, which commonly involves a kind of “natural selection” of scientific theories, or the ways of understanding scientific changes as a *revolution*, either conceptual or of other kind, where there is a clear discontinuity between before and after the revolutionary process. Thus, scientific change is underneath revolutions in science, in general, and conceptual revolutions, in particular. Here the references offer different approaches to scientific change, taking into account the perspectives of historicity, evolution and revolution.

⁹⁸ Cf. GONZALEZ, W. J., “Progreso científico, Autonomía de la Ciencia y Realismo,” *Arbor*, v. 135, n. 532, (1990), pp. 91-109.

⁹⁹ Cf. GONZALEZ, W. J., “Novelty and Continuity in Philosophy and Methodology of Science,” in GONZALEZ, W. J. and ALCOLEA, J. (eds.), *Contemporary Perspectives in Philosophy and Methodology of Science*, pp. 1-28; especially, pp. 4-9.

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3.2. On Revolutions in Science

Direct analyses of revolutions in science have been made by philosophers in many ways. Some focus on general aspects of scientific endeavors, such as in the case of Kuhn, while others have been oriented to revolutions in specific sciences, such as biology or economics. Undoubtedly, Kuhnian "scientific revolutions" and his "paradigms shifts" have been in the center of the attention for years. However, revolutions in some disciplines have also been very

influential, mainly in the discussion of Darwinism as a kind of revolution due to its effects for biology as well as for other disciplines.

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3.3. Conceptual Change and Conceptual Revolution

Cognitive sciences, either developed from a psychological framework or using another alternative (e.g., one based on artificial intelligence or more recently on neuroscience), have contributed to the analysis of conceptual changes. They are connected with the possibility and limits of conceptual revolutions. This cognitive approach has been associated to Thagard, but there are also other scholars that have carried out intense research, such as Nickles or Nersessian.

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¹⁰⁰ The paperback edition was issued in 1993. There is an Italian translation by Lorenzo Magnani and Emanuele Giorgi: *Rivoluzioni concettuali: Le teorie scientifiche alla prova dell'intelligenza artificiale*, Guerini e Associati, Milan, 1994. There is a Chinese edition in Taiwan, published by Hung Yeh Publishing in 2004.

CONCEPTUAL CHANGES AND SCIENTIFIC DIVERSITY: THE ROLE OF HISTORICITY *

Wenceslao J. Gonzalez

A frequent framework for analyzing the problem of the conceptual change and its repercussion on scientific diversity is given by the distinction between “evolution” and “revolution.”¹ On the one hand, the difference obviously has roots in the *history of science*, insofar as evolution and revolution involve an “arrow of time” in science that can be seen pointing backwards and forwards. Even though they have a different course, both need a temporal factor to develop their dynamics. But, on the other hand, the dissimilarity is *philosophical-methodological*, because evolution and revolution are characterizations of the advancement of science following a different path. Thus, they are related to the possibility of a scientific progress, including the conception of progress in science where historicity can match objectivity.²

Both descriptions of scientific dynamics — evolution and revolution — are connected to conceptual changes in science. In this regard, some thinkers of the cognitive approach have emphasized the relevance of analysis of *conceptual changes*. They have accepted the existence of scientific diversity based on cognitive factors such as concepts. Thus, within the contemporary philosophical-methodological proposals, there has been “cognitive revolution” open to an emphasis on concepts. In recent decades, this view has led to the consideration of “conceptual revolutions” in science.³ This standpoint has tried to fill the gap attributed to previous perspectives, such as the logico-methodological views — influential for four decades: from the 1920s to the 1960s — or even the approaches of the “historical turn,” which were dominant in the 1960s and 1970s.

Yet, in spite of the attempt to deal with “conceptual revolutions” in science, the cognitive approach has difficulties coping with the problem of *historicity*. Sometimes this problem seems to be ignored in very relevant publications in the field,⁴ while in other cases there is only an implicit

* This research project is supported by the Spanish Ministry of Science and Innovation (FFI2008-05948).

¹ There is the possibility of thinking of something that is both, evolutionary and revolutionary. This view has been suggested regarding the process of “conceptual change” understood as an evolutionary learning process and a revolutionary paradigm change. Cf. KEINY, S., “‘Conceptual Change’ as Both Revolutionary and Evolutionary Process,” *Teachers and Teaching*, v. 14, n. 1, (2008), pp. 61-72.

² For many years there has been a discussion on features of “scientific progress.” This has also been the case since 1980s onwards, cf. GONZALEZ, W. J., “Novelty and Continuity in Philosophy and Methodology of Science,” in GONZALEZ, W. J. and ALCOLEA, J. (eds.), *Contemporary Perspectives in Philosophy and Methodology of Science*, Netbiblo, A Coruña, 2006, pp. 1-28; especially, pp. 4-5, 13, and 15-16.

³ Cf. THAGARD, P., *Conceptual Revolutions*, Princeton University Press, Princeton, 1992. The “cognitive revolution” has also had consequences for particular sciences, such as economics, cf. EGIDI, M. and MARRIS, R. (eds.), *Economics, Bounded Rationality and the Cognitive Revolution*, E. Elgar, Aldershot and Brookfield, VT, 1992.

⁴ Cf. GOLDMAN, A. I. (ed.), *Readings in Philosophy and Cognitive Science*, The MIT Press, Cambridge, 1993. In this book of 38 chapters and 860 pages there is no entry in the subject index on historical aspects.

assumption through a variation of the situational contexts.⁵ This phenomenon is particularly relevant, because historicity is related to three successive levels: science, agents and the reality itself researched (above all, social and artificial). When the problem of historicity is seen from the viewpoint of concepts, the key aspect is the possibility of stating the existence of a historicity in the cognitive content and, at the same time, that the historical character — in any of the three levels pointed out — is not incompatible with objectivity.

Hence, the paper considers first the frequent framework of conceptual changes: evolution and revolution, a distinction that is different from the notion of “historicity.”⁶ Secondly, there is a characterization of the *context* of the problem of historicity in the realm of the cognitive approach. Thirdly, this context connects with issues on the specificity of the content and the role of the cognitive subject, which need to be considered. Fourthly, the analysis goes more deeply into the question of how to understand the change of the cognitive content. This task is developed here through reflection on the *conceptual revolutions* in science. Fifthly, the attention shifts to the role of *concepts*, insofar as they are the nexus with what is historically concrete, because researchers use concepts to make something real that changes intelligible. Finally, there are several considerations on the perspectives of the authors analyzed here in order to evaluate their contributions.

1. THE FREQUENT FRAMEWORK OF CONCEPTUAL CHANGES: EVOLUTION AND REVOLUTION

Scientific change has been frequently discussed following two main directions: as an evolution from previous stages and as a revolution in comparison with the dominant views, either present or past. Evolution and revolution are commonly seen as quite different approaches on the path of the development of science. In this realm, they often suggest two different philosophical-methodological frameworks: the idea of a large amount of continuity in the scientific progress, in the first case, and the existence of forms of clear discontinuity in the advancement of science, in the second.

Nevertheless, to change in terms of “evolution” from a previous stage in science (i.e., without a clear break from the earlier stance) can also mean quite different things,⁷ especially when the analysis takes into account key epistemological and methodological viewpoints. Thus, evolution might be a scientific unfolding from preceding contents, where there is still a logical trend between past and present contents, or it might be a more radical step forward, such as a

⁵ See for example THAGARD, P. (ed.), *Philosophy of Psychology and Cognitive Science*, Elsevier, Amsterdam, 2007. It is remarkable that in the full set of contributions to this volume (502 pages), the historical aspects appear very few times and mainly as “historical context” (pp. 413, 415, and 421-422). In this regard, the emphasis seems to be on external factors: we have “situated cognition;” and then human cognition is context-dependent, which includes historical contingencies: “knowledge is often relative to temporal, historical context,” SOLOMON, M., “Situated Cognition,” in THAGARD, P. (ed.), *Philosophy of Psychology and Cognitive Science*, p. 421.

⁶ There are studies that constantly use the notion of “evolution” and do not pay any particular attention to “historicity.” An example is in the research on complex systems and a set of cases of evolution (of matter, life, mind-brain, computability, artificial life, economics, human culture and society), cf. MAINZER, K., *Thinking in Complexity. The Computational Dynamics of Matter, Mind, and Mankind*, Springer, Berlin, 5th edition, 2007.

⁷ A large number of these uses of the term “evolution” can be found in GONZALEZ, W. J., “Evolutionism from a Contemporary Viewpoint: The Philosophical-Methodological Approach,” in GONZALEZ, W. J. (ed.), *Evolutionism: Present Approaches*, Netbiblo, A Coruña, 2008, pp. 3-59; especially, pp. 4-5, 7-10, 12-13, 17-18, 21-24, 31, 35-36, 40 and 45. See also BOWLER, P. J., *Evolution: The History of an Idea*, University of California Press, Berkeley, 1983; third edition, completely revised and expanded, 2003.

“Darwinian evolution,” which includes an open tree towards the future and makes the future outcome more difficult to predict.

Some philosophical-methodological approaches can be described in these kinds of evolutionary lines. On the one hand, there is an evolution of science understood as an accumulative process. Consequently, there is a scientific progress described basically in a linear way, as was commonly assumed in the views of many logical positivists or even logical empiricists.⁸ And, on the other, there is a characterization science that resembles a “Darwinian evolution,” insofar as there are factors such as a selection of theories and a kind of ramified tree open to the future. In fact, some versions of evolutionary epistemology like to be associated to this kind of approach, although sometimes they were actually closer to a Lamarckian than to a Darwinian position.⁹

Meanwhile a scientific change conceived in terms of a “revolution” also has a number of possibilities. Among them are two well-known conceptions: Thomas Kuhn’s “scientific revolutions” and Paul Thagard’s “conceptual revolutions.” In the Kuhnian tout-court revolution of his initial historiographical period the changes are radical and context-dependent. His book *The Structure of Scientific Revolutions* accepts some similarities between the revolutions in science and the political revolutions.¹⁰ In addition, the changes depend directly upon the scientific community: they make revolutions in science through “paradigm shifts,” where the previous and posterior contents are incommensurable. Meanwhile Thagard’s “conceptual revolutions” develops an alternative to that position. It is based on a set of cognitive changes made upon variations in the scientific concepts.¹¹

Commonly, these conceptions of scientific change — evolution and revolution — are seen from the point of view of the “intensity” in the level of modifications introduced through the advancement of science. But there are other relevant differences in the scientific change — both backwards and forwards — due to the kind of variation introduced in the particular science discussed. These variations can lead to a scientific diversity according to two main routes: internal and external. Thus, the variations can emphasize the internal elements of science as a human endeavor (language, structure, knowledge, method, etc.), or they can put a special stress on the relevance of external factors surrounding scientific activity (social, economic, cultural, political, etc.).

If the emphasis is on internal elements of science, then the role of *conceptual changes* is certainly more important than in the case of the special relevance of external factors. Thus, in order to grasp the variations in science — both actual and possible ones —, the analysis of the scientific diversity based on conceptual changes takes into account primarily those elements

⁸ Historically, there were at least three successive methodological approaches based on an accumulative view of scientific progress: those build up on the notions of “verification,” “verifiability,” and “empirical confirmation.” Cf. SUPPE, F., “The Search for Philosophic Understanding of Scientific Theories,” in SUPPE, F. (ed.), *The Structure of Scientific Theories*, University of Illinois Press, Urbana, 1974 (2nd edit. 1977), pp. 1-241; especially, pp. 16-56. Their views can fit with some versions of “evolution” in scientific concepts.

⁹ Among the epistemological conceptions based on evolutionary roots is CAMPBELL, D. T., “Evolutionary Epistemology,” in SCHILPP, P. A. (ed.), *The Philosophy of Karl Popper*, Open Court, La Salle, 1974, IL, vol. 1, pp. 413-463. On this topic there are interesting remarks in HODGSON, G. M., “Is Social Evolution Lamarckian or Darwinian?,” in LAURENT, J. and NIGHTINGALE, J. (eds.), *Darwinian and Evolutionary Economics*, E. Elgar, Cheltenham, 2001, pp. 87-120.

¹⁰ Cf. KUHN, TH. S., *The Structure of Scientific Revolutions*, International Encyclopedia of Unified Science: Foundations of the Unity of Science, v. 2, n. 2, The University of Chicago Press, Chicago, 1962 (2nd ed., 1970); especially, pp. 92-94.

¹¹ Cf. THAGARD, P., *Conceptual Revolutions*, pp. 6-9 and 13-33.

(language, structure, knowledge, method, etc.) of this human endeavor. Meanwhile, when the focus is on modifications introduced by concepts, the other factors surrounding scientific activity (social, economic, cultural, political, etc.) only play a secondary role regarding this type of scientific change.

These options on changes in science and scientific diversity — mainly, evolution or revolution, either internally or externally focused — assumed that scientific diversity varies a lot according to the conception used to comprehend conceptual changes. If the history of science is taken seriously to do philosophy and methodology of science, then the mere *evolution* — either in the accumulative way or in the ramified tree — seems insufficient to grasp the scientific diversity that we can see in science nowadays. But some versions of scientific *revolutions* go too far, as happens in the case of the initial Kuhnian characterization of revolutions, which describes a relativistic scientific change upon the shoulders of the variable scientific communities.

Insofar as the focus is on *scientific revolutions* and the perspective is open to the idea of possible *objective contents* in science, then there is a set of issues at stake. Among them, there are some particularly relevant ones here. (i) How to distinguish between an “evolution” and a “revolution” in the development of science? (ii) What is the “core” of a scientific revolution? (iii) How does it affect scientific diversity? These questions are underpin the analysis in this paper (and, *de facto*, they underlie the whole book).

Prima facie, the distinction between “evolution” and “revolution” is made in terms of the intensity in the change (in this case, of the conceptual change). Frequently, it is an issue of degree rather than something more substantial or even “essential.” But if the emphasis is on the level of intensity in the change, then the distinction might be blurred, insofar there is no a clear-cut frontier between both notions. Meanwhile when there is an acceptance of new categories connected to novel facts, the difference is clearer than in the previous case. “Categories” are key concepts that are relevant at several levels: semantic, logical, epistemological, methodological, ontological, ...

From the “internal” point of view, the “core” of a scientific revolution has a key element in the conceptual changes that lead to new categories connected to novel facts. In this regard, conceptual revolutions are then deep conceptual changes that involve categorical modifications in science and, consequently, they bring together scientific diversity. This aspect usually involves historicity and an increase of the level of complexity.¹² Commonly, conceptual revolutions are linked to a “cognitive revolution,” a new focus of intellectual character that it is linked to the development of the cognitive sciences.

Diversity in science requires conceptual changes. The historicity of concepts supersedes the frequent interpretative schemas of “evolution” and “revolution.” History of science shows us examples of the conceptual continuity and conceptual discontinuity, slow changes in contents and rapid changes, shallow changes in some cases and very deep ones in others, conceptual creativity and reinterpretation of previous concepts, etc. In other words, the

¹² On the notion of “complexity” and the main kinds, see RESCHER, N., *Complexity: A Philosophical Overview*, Transaction Publishers, New Brunswick, NJ, 1998, pp. 1-24. In the case of economics, this can be seen in GONZALEZ, W. J., “Complexity in Economics and Prediction: The Role of Parsimonious Factors,” in DIEKS, D., GONZALEZ, W. J., HARTMAN, S., STADLER, F., UEBEL, TH. and WEBER, M. (eds.), *Explanation, Prediction, and Confirmation*, Springer, Dordrecht, 2011, pp. 319-330.

distinction “evolution” and “revolution” does not fit the motley character of the scientific concepts. This requires serious consideration of “historicity” of concepts and how they are open to diversity and complexity.

2. CONTEXT OF THE PROBLEM OF HISTORICITY IN THE REALM OF THE COGNITIVE APPROACH

Among the concerns on the cognitive approach is the difficulty that it has in order to articulate the problem of *historicity*.¹³ This is an important feature that is present in three successive *levels of analysis*: science, agents and the reality itself researched (above all, social and artificial). 1) Historicity (*Geschichtlichkeit/historicidad*) is a trait of science, in general, and each science, in particular. This facet can be found in the whole set of constitutive elements of science, such as language, structure, knowledge, method, activity, aims and values.¹⁴ 2) Historicity configures the agents themselves involved in the development of scientific research, insofar as they are human beings within a historical context. 3) Historicity is a characteristic of the reality itself that is researched (above all, in the social and artificial realms).

Each level of the cognitive approach — science, agents, and the reality itself researched — present some contours that add extra *difficulties* for the problem of historicity. First, there is the problem of the specificity in the content itself that is proper of “cognitivism,” because the cognitive approach is frequently presented as an interdisciplinary thematic realm but is sometimes described as merely multidisciplinary. Second, there is the issue of how to understand the role attributed to the cognitive subject in the cognitive task, due to the proposed ascription made by the cognitive approach to the machines,¹⁵ in addition to humans. Third, there is the concern about the dynamics itself of reality, especially in the social and artificial spheres. Commonly, in addition to the structural complexity in these spheres,¹⁶ there is a complex dynamics. This dynamics involves variability, which makes the existence of objective concepts more difficult.

When the problem of historicity is seen from concepts, the key is then in the possibility of asserting a historicity *de facto* in the cognitive content and, at the same time, in that the historical character — in each level point out: science, agents, and reality — is not incompatible with objectivity. But this involves an adequate characterization of the *concepts*. Thus, a timeless or a priori vision of concepts is not possible to deal with changes present in science (which include errors recognized later), the existence of variable social environments (epochs, cultures, civilizations, etc.), where the agents acquire or develop knowledge, and the mutability of the realities themselves that have a human origin.

¹³ This section and the following ones are build on in GONZALEZ, W. J., “El enfoque cognitivo en la Ciencia y el problema de la historicidad: Caracterización desde los conceptos,” *Letras (Universidad Nacional Mayor San Marcos, Perú)*, v. 79, n. 114, enero-diciembre (2008), pp. 51-80.

¹⁴ On those components as constitutive elements of science see GONZALEZ, W. J., “The Philosophical Approach to Science, Technology and Society,” in GONZALEZ, W. J. (ed.), *Science, Technology and Society: A Philosophical Perspective*, Netbiblo, A Coruña, 2005, pp. 3-49; especially, pp. 10-11.

¹⁵ Cf. SIMON, H. A., “Machine as Mind,” in FORD, K. M., GLYMOUR, C. and HAYES, P. J. (eds.), *Android Epistemology*, AAAI/MIT Press, Menlo Park, CA, 1995, pp. 23-40. On his conception, see KLAHR, D. and KOTOVSKY, K. (eds.), *Complex Information Processing: Essays in Honor of Herbert A. Simon*, Erlbaum, Hillsdale, NJ, 1989.

¹⁶ Regarding structural complexity, the two main levels of complexity are epistemological and ontological, each with a set of sub-levels. See RESCHER, N., *Complexity: A Philosophical Overview*, pp. 1-24; especially, pp. 8-21; and GONZALEZ, W. J., “Complexity in Economics and Prediction: The Role of Parsimonious Factors,” in DIEKS, D., GONZALEZ, W. J., HARTMAN, S., STADLER, F., UEBEL, TH. and WEBER, M. (eds.), *Explanation, Prediction, and Confirmation*, pp. 319-330; especially, section 2: pp. 321-325.

Within the cognitive sciences, the problem of historicity connects with the issues on the *specificity* of the cognitive content, which is the standpoint to consider its variability through time, and with the characterization of the cognitive *subject*, who commonly knows in a given situation, which frequently changes. Thus, regarding the first level of the problems mentioned, cognitivism — above all, in the most influential versions — has usually insisted on interdisciplinarity and habitually leaves aside multidisciplinary. Concerning the second level of problems, the cognitive approach is normally focused on the individual agents. Ordinarily, this view sees the existence of a “social subject” who has genuine cognitive properties as problematic. And at the third level of problems, the dynamics itself of the reality leads us towards “the historical,” a field explored by the science of history.¹⁷

Consequently, the levels of analysis regarding science and the agents — insofar as they deal with the knowledge of *extramental* or reality existing outside the mind — should be taken into account in order to articulate the problem of historicity in the cognitive approach when the perspective is the characterization from the concepts. Thus, after attending here to the *context* of the problem of historicity in the realm of cognitivism, the attention goes now to the connected issues on the specificity of cognitive content and the role of the knowing subject in this regard.

3. THE ISSUES ON THE SPECIFICITY OF CONTENT AND THE ROLE OF THE KNOWING SUBJECT

Frequently, this scientific realm is referred to in the plural: *cognitive sciences*.¹⁸ This suggests that we are in an *interdisciplinary* environment, if we accept that there is a common axis that articulates the contributions made by different disciplines (psychology, artificial intelligence, linguistics, etc.). But it might be also possible that we end up being in a *multidisciplinary* environment, if what is being offering is a succession of contributions that work out as if they were a set of superimposed layers or a mix of elements from diverse disciplines. Both views — the interdisciplinary option and the multidisciplinary position — assume that in the cognitive sciences converge a large amount of disciplines.

Nevertheless, the singular form — *cognitive science* — might be used, mainly when the aim is to emphasize that it has a specific scientific status which is different from other disciplines that were its original milieu or with which it is directly connected. This was what Herbert Simon

¹⁷ From an ontological point of view, “*the historical (lo histórico)* is something that involves several features, which connect with the historicity of the human being and the society: (i) the historical *has happened already* (even though it might be possible that some events actually going on, due to their importance, could be considered as “historical”), because the having happened (*el haber acontecido*) is a requirement to entry in a period to be studied by history (to pass into “the pages of history”); (ii) the historical possesses some kind of *relevance* (causal or not), because not everything that is happening or has happened is “History:” there are events that are not *historical*; (iii) although many changes do take place through the time, there exist a historical continuity, which makes always possible to link the different historical stages and to refer to concrete realities (places, persons, etc.); (iv) human and social historicity render *novelty*, which makes possible to affirm that there is no two identical historical periods in all counts (which involves the absence of “qualitative identity”); (v) the historical grounds (*deja huella en*) in the posterior life of society, because it contributes to the *configuration* of human and social activity: history is not merely something that accompanies society, such as the temporality, but contributes to its articulation and identity.” GONZALEZ, W. J., “Caracterización del objeto de la Ciencia de la Historia y bases de su configuración metodológica,” in GONZALEZ, W. J. (ed.), *Acción e Historia. El objeto de la Historia y la Teoría de la Acción*, Publicaciones Universidad de A Coruña, A Coruña, 1996, pp. 57-58.

¹⁸ Cf. WILSON, R. A. and KEIL, F. C. (eds.), *The MIT Encyclopedia of the Cognitive Sciences*, The MIT Press, Cambridge, MA, 1999.

did when he proposed cognitive science as the “newest science of the artificial.”¹⁹ However, this territory of research about knowledge has many ways of access, as is reflected in Simon’s conception, which is interdisciplinary. Thus, he includes *de facto* contents of several disciplines related to “knowing,” principally philosophy, psychology and artificial intelligence.²⁰

Moreover, almost all Simon’s intellectual trajectory can be seen from a cognitive perspective,²¹ because only occasionally does he go deeply into motivational or affective factors. From a perspective of clear cognitive preference, he develops an effective contribution to the characterization of human rationality. He does so through the three successive models of rationality that he proposes: (i) the model of administrative decision maker; (ii) the model of the universal decision maker; and (iii) the model of the symbolic problem solver.²²

De facto, there is in Simon interdependence between his cognitive approach, his vision of human rationality and his contributions to sciences such as economics.²³ In his conception, when he thinks of economics in terms of bounded rationality, the preference is for individualism, both epistemological and methodological. Thus, the agent who makes the decisions is, in principle, an individual subject who has a limited capacity to compute cognitive contents.²⁴ His or her decisions are made within a clearly situational context, where he or she looks for *satisficing* without seeking in fact to maximize, because the capacity of computation of the agent is limited. From this angle, Simon deals with the behavior of the organizations,²⁵ which to a large extent depends on the behavior of the individual agents.

Regarding this set of topics, within the sphere of the relation between cognitive psychology and behavioral economics, I asked Simon about an issue I did not see in his papers: the problem of historicity in the science of economics. In 1996 the Nobel Prize of 1978 had not yet published an article on the historical side of economics, which is at the same time social science and a science of the artificial. In this regard, he accepted my invitation to write a paper on this issue. This article was published in 1998 with the title *Economics as a Historical Science*,²⁶ which belongs to a volume that I coordinated on philosophy and methodology of economics.

¹⁹ Cf. SIMON, H. A., “Cognitive Science: The Newest Science of the Artificial,” *Cognitive Science*, v. 4, (1980), pp. 33-46. Cf. NEWELL, A. and SIMON, H. A., “Computer Science as Empirical Inquiry: Symbols and Search” [1975 ACM Turing Award lecture], *Communications of the Association for Computing Machinery*, v. 19, n. 3, (1976), pp. 113-126; reprinted in BODEN, M. (ed.), *The Philosophy of Artificial Intelligence*, Oxford University Press, Oxford, 1990, pp. 105-132.

²⁰ Even in the case of using the expression in singular, it is frequent to mention an explicit relation with some of the disciplines pointed out, cf. THAGARD, P. (ed.), *Philosophy of Psychology and Cognitive Science*, *passim*.

²¹ Cf. SIMON, H. A., “On Simulating Simon: His Monomania, and its Sources in Bounded Rationality,” *Studies in History and Philosophy of Science*, v. 32, n. 3, (2001), pp. 501-505. In the final bibliography of the present text there is a number of his papers directly related to *Cognitive Science*.

²² Cf. DASGUPTA, S., “Multidisciplinary Creativity: The Case of Herbert A. Simon,” *Cognitive Science*, v. 27, (2003), pp. 683-707; especially, pp. 694-695. They have their origin in the thematic realms that he studied through his large trajectory: political science, the first one; economics and philosophy, the second; and artificial intelligence, the third.

On this topic, see GONZALEZ, W. J., “Configuración de las Ciencias de Diseño como Ciencias de lo Artificial: Papel de la Inteligencia Artificial y de la racionalidad limitada,” in GONZALEZ, W. J. (ed.), *Las Ciencias de Diseño: Racionalidad limitada, predicción y prescripción*, Netbiblo, A Coruña, 2007, p. 54, note.

²³ Cf. EGIDI, M. and MARRIS, R. (eds.), *Economics, Bounded Rationality and the Cognitive Revolution*, *passim*.

²⁴ Simon does not dismiss the social entities, but the emphasis goes to the individual agents.

²⁵ On his view of organizations, see SIMON, H. A., “Complex Systems: The Interplay of Organizations and Markets in Contemporary Society,” *Computational and Mathematical Organization Theory*, v. 7, (2001), pp. 79-85.

²⁶ SIMON, H. A., “Economics as a Historical Science,” *Theoria*, v. 13, n. 32, (1998), pp. 241-260.

Until that moment, Simon was not attracted by the study of the historicity of knowledge and its incidence in economics.²⁷ But, in my judgment, the component of historicity in knowledge is key to understanding science, in general, and the sciences that deal with social realities and artificial designs, in particular. The proposal made by Simon on economics as a historical science appeals above all to changes related with the environment. Thus, he first points out the facets considered by the mainstream economic history (technological change, variations in institutional context and in the categories of exogenous institutional variables²⁸). Thereafter, he insists on the dependence of historicity from the variables related to bounded rationality of economic agents, who need to adjust to the environment around them, that embraces them.²⁹

Commonly, mainstream economic history tends towards historicity of the *reality itself* that is researched. Thus, the technological innovations, the surge of new institutions and other changes related to economic entities (modifications in utility functions, novelties in the function of production or new laws of property) involve variability in what is studied. It is something in principle observable and, therefore, beyond the *extramental* (i.e., a reality existing outside our minds).

Simon especially emphasizes the opposite pole of the relation: the variability of the agents in relation to their economic environment. Hence, he insists on the changes of their knowledge, in their ability to estimate consequences of the decisions, in the variations in the focus of attention, etc. But he does not pay attention to the elements to consider the historicity of science as such from a conceptual, due presumably to the initial formation received from logical positivists of the University of Chicago.³⁰

His proposal is made in terms of adaptive rationality of an evolutionary kind. *De facto*, Simon's approach is more Lamarckian than Darwinian,³¹ because it presupposes a basically accumulative adaptive process, which is distant from the ramification of options that is characteristic of the Darwinian viewpoint. From an overall perspective, it seems to me that his reflection on historicity is insufficient.

On the one hand, it is possible to begin with changes, mainly cognitive, to get an adjustment to the social environment; but the historicity of the agents is more complex than that form of

²⁷ In some of his papers, Simon mentioned occasionally "paradigms." He even uses the expression "paradigm shifts," but he does not go deeply into that vision of the historicity of science. He uses those terms to indicate a wider interpretative framework, but without considering how the scientific change takes place. Cf. SIMON, H. A., "Bounded Rationality in Social Science: Today and Tomorrow," *Mind and Society*, v. 1, n. 1, (2000), pp. 25-39; especially, p. 26.

²⁸ In this regard, he writes that "a partial catalogue of exogenous institutional variables (and candidates for endogenization) would include: (1) changes in the utility function, with consequent changes in demand and in savings rates; (2) changes in the production function, resulting from technological change and other factors, and with consequent changes in supply; and (3) changes in the laws of property, with consequent effects upon positive and negative externalities, the appropriability of inventions and powers of government to redistribute income and wealth," SIMON, H. A., "Economics as a Historical Science," p. 251.

²⁹ Simon suggest that one should "take into account (1) continuing changes in knowledge and information (both knowledge about economics and other knowledge about the world), (2) changes in human ability to estimate consequences of actions, (3) changes in the institutional setting within which economic behavior takes place, (4) changes in the focus of attention and related changes in beliefs and expectations. I will add, for they belong among the belief-dependent variables, (5) changes in human altruism and (6) in group identification," SIMON, H. A., "Economics as a Historical Science," p. 251.

³⁰ Cf. SIMON, H. A., *Models of my Life*, Basic Books, N. York, NY, 1991, p. 44.

³¹ Cf. HODGSON, G. M., "Is Social Evolution Lamarckian or Darwinian?," in LAURENT, J. and NIGHTINGALE, J. (eds.), *Darwinian and Evolutionary Economics*, p. 87.

behavior (it is rather an expression of a human activity).³² And, on the other hand, we need to consider the conceptual changes, the variations in those concepts that we use to focus on the reality that is research. They might be part of “theories,” “paradigms,” “research programs,” or other new interpretative frameworks.

Now, from the cognitive point of view, there is a need for an alternative to Simon that expressly takes into account the conceptual change in science from the perspective of historicity. Paul Thagard has considered more elements of historicity than the previous option, both in science, in general, and in the cognitive contents, in particular. He has done this in his characterization of the conceptual revolutions,³³ which he has used for analyzing later concrete cases of biomedical research.³⁴ His proposal seeks also to preserve scientific rationality during the conceptual change. In addition to the delineation of the contents of the concepts with more refinement than Thomas Kuhn, who is here the point of comparison, Thagard’s position seems more robust than the “incommensurability” of paradigms of the first Kuhnian period.³⁵

4. HOW TO UNDERSTAND THE CHANGE OF THE COGNITIVE CONTENT: THE REFLECTION ON THE CONCEPTUAL REVOLUTIONS IN SCIENCE

Undoubtedly, historicity affects the diverse components of science (semantic, logic, epistemological, methodological, ontological, axiological and ethical). But usually it is better appreciated within the ontological area, because this is the territory where novel facts acquire more visibility. In ontology of science there is a duality: on the one hand, science is a human activity of social character, which constitutes its status as entity; and, on the other, science gives us a detailed image of reality (it articulates the world in the natural, social and artificial contexts). Both sides — human activity and the detailed image of reality — are embedded by historicity.

Initially, the side of human *endeavor* is emphasized, and this undertaking is diversified in several aspects. (i) Science is *eo ipso* revisable, because it is in itself *temporal* and open to new possibilities in the future. (ii) Ontologically, historicity involves a relation with *praxis*,

³² This can be considered in terms of “activity” instead of “behavior.” They are two different concepts. 1) Human activity articulates mental *acts* — the internal element — with actions — the external component —, which those originate. Meanwhile human behavior is, in principle, only at the level of the observable performance of the agents. 2) Activity has an immediate *practical* character: it includes *praxis* — it is doing something which affects its reality —, whereas behavior has a less diversified scope, mainly when it is understood as instinctive (close to animal behavior). 3) Activity has in itself *historicity*: human activity is *eo ipso* historical, not only in the sense of *having* time, but also in the deepest sense of occurring and developing precisely *with* time. This historicity affects the decision making process and it should be included among the elements to be studied. Behavior, on the contrary, has a more static constitution, because it can be considered without especial concern for historicity (a very well known example is behaviorism). 4) Activity has a very close link with *language*, more than behavior. So, there is no problem in the connection between action and language (such as in the case of “speech acts”) whereas there are criticisms regarding behavior and language (e. g., with Skinner’s “verbal behavior” or Quine’s proposals). 5) Activity has both a *descriptive* and a *normative* sphere, because there are genuine social actions which require norms to rule it properly (either ethically or legally), whereas behavior is more descriptive than normative. Cf. GONZALEZ, W. J., “Caracterización del objeto de la Ciencia de la Historia y bases de su configuración metodológica,” in GONZALEZ, W. J. (ed.), *Acción e Historia. El objeto de la Historia y la Teoría de la Acción*, p. 101. On the features of “act,” “action” and “activity” in the context of economics, cf. GONZALEZ, W. J., “Economic Prediction and Human Activity. An Analysis of Prediction in Economics from Action Theory,” *Epistemologia*, v. 17, (1994), pp. 264-268.

³³ In his book *Conceptual Revolutions*, published in 1992, Thagard first analyzes the revolutions understood from concepts and later he considers several “conceptual revolutions.”

³⁴ Cf. THAGARD, P., *How Scientists Explain Disease*, Princeton University Press, Princeton, 1999.

³⁵ Cf. KUHN, TH. S., *The Structure of Scientific Revolutions*, 2nd ed., pp. 103, 148-150 and 165.

understood as practical human activity. (iii) Scientific activity is constitutively social, even though some concrete individuals might have a protagonist role. Thus, from the viewpoint of entities, research activity is not constrained to pure temporality: it is not something that only *has* time or is developed merely in a chronological framework.³⁶

As happens with the human agents that make science, there is something more here than the “arrow of time:” scientific undertaking involves a prospective view and retrospective sight of the real (either natural, social or artificial). Through scientific prediction, the possible future is taken into account. There is also an active vista on the past, especially insofar as it has conditioned the present. The cognitive content acquired through this activity is located in these coordinates and offers us an ontological articulation when it gives a *detailed image* of reality. Thus, the attention to the future (e.g., predictions about the climate change) is grounded in the knowledge available from the present (the actual state of the known variables) and also in the consideration of the trajectory of the past that we have been able to reconstruct.

Two sides of historicity appear when the emphasis is on science as human activity. On the one hand, the “internal historicity” of the content, i.e., the scientific changes due to processes of self-correctness; and, on the other, the “external historicity” given by the social environment when the discovery and justification of what has been found occurs. But we need to consider the existence of extremes that reject the option proposed here.

One extreme is fixism or complete stability. If the attention shifts to the *structure* itself of knowing instead of being the focus of the activity, then we can offer a timeless cognitive mould in science. Kuhn tried to avoid it by using variable conceptual schemes, which lead him towards being a “Kantian with moveable categories.”³⁷ But the opposite extreme to this timelessness might also be possible, an option which can be found in forms of historical relativism. This is what happens if an alleged *congenital variability* of the cognitive content of science is assumed or when there is an acceptance of an *intrinsic volatility* regarding the social environment. Through of the relativistic options the objectivity of science will be automatically diluted.

Kuhn became deeply involved in this debate after *The Structure of Scientific Revolutions*. Since then it has been frequent to distinguish between “evolution” and “revolution” in science, which have been associated to the notions of “normal science” and “revolutionary science.” But it happens that “evolution,” if understood as by Charles Darwin, then it is not lineal at all. His book on *The Origin of Species* shows that he sees evolution as a ramified tree. Thus, he visualizes evolution through natural selection according to the “tree of life,” where each branch is open and, therefore, it is not easy to predict what will come thereafter.³⁸

³⁶ “Temporality” is less than “historicity.” This can be seen above all in the science of history. “Because, while doing history, the mutation of reality generated by the human actions is taken into account; and the agents that performed that modification as well as the framework where the actions take place are under changes that *give back* on their own reality: both are ontologically historical. Thus, historicity adds a *new dimension* to temporality: it involves a change that affects agents as such and has repercussion on the existing temporal structures. In fact, the historical undertaking includes progresses and regresses, influences from the past and expectation for the future... that configure the agents themselves and the society that they are inserted,” GONZALEZ, W. J., “Caracterización del objeto de la Ciencia de la Historia y bases de su configuración metodológica,” p. 89.

³⁷ KUHN, TH. S., “A Discussion with Thomas S. Kuhn,” in KUHN, TH. S., *The Road Since Structure: Philosophical Essays, 1970-1993, with an Autobiographical Interview*, edited by James Conant and John Haugeland, The University of Chicago Press, Chicago, 2000, p. 264.

³⁸ Cf. GONZALEZ, W. J., “Evolutionism from a Contemporary Viewpoint: The Philosophic-Methodological Approach,” in GONZALEZ, W. J. (ed.), *Evolutionism: Present Approaches*, especially, p. 7.

“Revolution,” understood as by Kuhn, involves undoubtedly a radical cognitive change, in addition to other changes (of practices, of instruments, of the social environment, etc.). In his approach, this leads to the problem of “incommensurability,” which in his thought acquires three successive forms. They belong to three stages in his philosophy: 1) the initial period of philosophical-methodological *configuration*, which goes from the previous papers to *The Structure of Scientific Revolutions* to approximately 1968; 2) the period of *revision, clarification and enlargement* of the initial theses, which starts around 1969 and embraces at least all the decade of 1970s; and 3) the new creative phase of *linguistic* character, which is noticeable since 1982, when he presented his famous paper *Commensurability, Comparability, Communicability*.³⁹ In each stage, “revolution” has specific nuances, up to the point of offering de facto three different characterizations of “scientific revolution.” Thus, although Kuhn cultivated cognitive perspectives,⁴⁰ he saw how Paul Thagard presented a global alternative to his position in the book *Conceptual Revolutions*, which might be better appreciated if it is compared with the initial stage of *The Structure of Scientific Revolutions*.

What Thagard offered then was an interesting articulation of conceptual revolutions,⁴¹ which has led him recently to the study of neuroscience, a realm where there has been a deep conceptual change.⁴² He emphasizes that science cannot be understood without the role of the *conceptual change*. This ratifies the historical character of science, a feature that has been highlighted since the “historical turn” of the 1960s.⁴³ Obviously, this feature should be considered in the cognitive sciences themselves, which cannot be as timeless: they are also involved in the conceptual change, as can be seen in the variations of the artificial intelligence.⁴⁴

Expressly, Thagard is aware of the need to integrate the cognitive and the social in order to explain scientific change.⁴⁵ In his book on conceptual revolutions he seeks an aim of the cognitive sciences. In fact he tries “to provide a theory of conceptual change that unites philosophical, psychological, and computational approaches and that applies to all the major

³⁹ Cf. GONZALEZ, W. J., “Las revoluciones científicas y la evolución de Thomas S. Kuhn,” in GONZALEZ, W. J. (ed.), *Análisis de Thomas Kuhn: Las revoluciones científicas*, Trotta, Madrid, 2004, pp. 15-103; especially, pp. 46-48. See also IRZIK, G., “Thomas Kuhn: The Road Since *Structure*,” *Philosophy of Science*, v. 68, n. 4, (2001), pp. 573-575; especially, p. 574.

⁴⁰ Cf. NERSESSIAN, N. J., “Kuhn, Conceptual Change, and Cognitive Science,” in NICKLES, TH. (ed.), *Thomas Kuhn*, Cambridge University Press, Cambridge, 2003, pp. 178-211. Cf. BARKER, P., CHEN, X. and ANDERSEN, H., “Kuhn on Concepts and Categorization,” in NICKLES, TH. (ed.), *Thomas Kuhn*, pp. 212-245.

⁴¹ His proposal is analyzed in GONZALEZ, W. J., “Towards a new Framework for Revolutions in Science,” *Studies in History and Philosophy of Science*, v. 27, n. 4, (1996), pp. 607-625. Pages 609-612 are used as the basis for the present section.

⁴² This was clear in March 2009, when he presented two papers at the University of A Coruña during the conference on *Conceptual revolutions: From Cognitive Sciences to Medicine*, and it is also visible now in the two chapters that Thagard has prepared for this book.

⁴³ The “historical turn” that Kuhn started was later consolidated by Imre Lakatos. The *historical turn* has left as lasting remains the relevant relation between history of science and philosophy and methodology of science. The historical character is based upon science as a human activity.

⁴⁴ Cf. FLORIDI, L., *Philosophy and Computing*, Routledge, London, 1999; and FLORIDI, L. (ed.), *The Blackwell Guide to the Philosophy of Computing and Information*, Blackwell, Oxford, 2004.

⁴⁵ Cf. THAGARD, P., “Explaining Scientific Change: Integrating the Cognitive and the Social,” HULL, D., FORBES, M. and BURIAN, R. M. (eds.), *Proceedings of the 1994 Biennial Meeting of the Philosophy of Science Association*, Philosophy of Science Association, East Lansing, MI, vol. 2, 1995, pp. 298-303.

scientific revolutions.”⁴⁶ It is an interdisciplinary view that, starting from epistemological and methodological naturalism, gives special relevance to the empirical dimension (the contributions of psychology and artificial intelligence). Thus, the vision of “conceptual revolutions” differs from Kuhn’s “scientific revolutions,” which in the initial period were openly historiographical. The main differences are in two central points of the scientific dynamics: in the rationality of the conceptual change and in the commensurability of theories.

Both aspects — rationality and commensurability — are defended by Thagard in his theory of explanatory coherence, which criticizes the impediments to rationality in science and reaffirms the comparability of scientific theories. Thus, he accepts the existence of objective elements in the interpretation of revolutions. This distances him from several factors that can be a basis for relativism: a) the “Kuhnian conversion” in the election of paradigm;⁴⁷ b) the primacy of the sociological viewpoint of the revolutionary change — the preference for the communities —; and c) the linguistic emphasis for understanding scientific revolutions in terms of translation.⁴⁸

Thus, it seems clear that Thagard rejects the purely subjective explanation of conceptual change, the relativistic option of sociological kind and the interpretation of conceptual change as mere “translation” of languages.⁴⁹ His vision is then twofold: “Kuhn’s general view of scientific revolutions and his accounts of particular scientific episodes must be questioned, but his basic claim that the development of scientific knowledge includes revolutionary changes can be sustained.”⁵⁰

Following these coordinates, in order to characterize the conceptual revolutions Thagard states initially several theses: (i) scientific revolutions involve major transformations in conceptual and propositional systems; (ii) conceptual systems are primarily structured via kind-hierarchies and part-hierarchies; (iii) new theoretical concepts generally arise by mechanisms of conceptual combination; (iv) propositional systems are primarily structured via relations of explanatory coherence; (v) new theoretical hypotheses generally arise by abduction; and (vi) the transition to new conceptual and propositional systems occurs because of the greater explanatory coherence of the new propositions that use the new concepts.⁵¹

Thagard studies *concepts and conceptual systems* in order to provide the basis for a theory of revolutionary conceptual change. Initially, the focus is on the philosophical theories of concepts and later on the positions of cognitive psychology and artificial intelligence. In this regard, he summarizes important views of concepts in history of philosophy and also discloses his own perspective: “concepts are mental entities that are largely learned and open.”⁵² Philosophically, he emphasizes conceptual change over the belief revision. Thus, he considers that the growth of

⁴⁶ THAGARD, P., *Conceptual Revolutions*, p. 10. In psychology the existence of a “cognitive revolution” is assumed, cf. GREENWOOD, J., *A Conceptual History of Psychology*, McGraw-Hill, New York, 2009, ch. 12: Cognitive revolution, pp. 523-564.

⁴⁷ This is one of the axes of the “paradigm shift” of his first period, cf. KUHN, TH. S., *The Structure of Scientific Revolutions*, 2nd ed., pp. 150-152.

⁴⁸ Cf. KUHN, TH. S., “Commensurability, Comparability, Communicability,” in ASQUITH, P. D. and NICKLES, TH. (eds.), *PSA 1982. Proceedings of the 1982 Biennial Meeting of the Philosophy of Science Association*, vol. 2, Philosophy of Science Association, East Lansing, MI, 1983, pp. 669-688.

⁴⁹ Cf. THAGARD, P., *Conceptual Revolutions*, pp. 109-117.

⁵⁰ THAGARD, P., *Conceptual Revolutions*, p. 4.

⁵¹ Cf. *Conceptual Revolutions*, pp. 7-9.

⁵² THAGARD, P., *Conceptual Revolutions*, p. 19.

scientific knowledge cannot be understood in pure terms of belief revision without any relation to conceptual change.

After the characterization of concepts and conceptual systems, Thagard puts forward his description of *conceptual change*, taking the chemical revolution as a key example.⁵³ In his analysis, a theory of conceptual change which adequately accounts for conceptual revolutions requires three elements: a) to describe the mechanism by which discoverers of new conceptual systems can build up their new systems; b) to explain how the new conceptual system can come to replace the old; and c) to provide an account of how additional members of the scientific community can acquire and accept the newly constructed conceptual system.⁵⁴

Even though this theory of conceptual change is conceived as an alternative to the Kuhnian structure of revolutions in science,⁵⁵ it assumes *de facto* something central to Kuhn's views: scientific revolutions are mainly psychological and sociological instead of being "logical" or methodological. Hence, in spite of his explicit criticisms, Thagard describes the computational mechanisms as forming part of the psychology of individuals and having sociological consequences. Therefore, scientific change is psychological — the change in the mental representations: the concepts — as well as sociological, because, for him, scientific revolution occurs only when a scientific community as a whole adopts the new conceptual system.⁵⁶

Moreover, when Thagard raises the question of what *concepts* are,⁵⁷ he looks for a reply in the field of cognitive psychology. Accordingly, what he obtains is an answer to the problem of *how* they operate, because *what* concepts are is a philosophical question. In my judgment, he tries to avoid subjectivism and is well oriented in his criticism of understanding the growth of scientific knowledge purely in terms of belief revision. But he insists on concepts and propositions as *mental representations*.⁵⁸

Here is one of the weaknesses of Thagard's approach, which affects the grounding of his building of the "conceptual revolutions." To characterize the notion of "concept" from the idea of "mental representation" is insufficient. On the one hand, it is correct to state that one of the sides of the concept is *representation*, insofar as it involves otherness (i.e., alterity) and an intellectual presentation of something *extramental* (i.e., outside the mind). But, on the other hand, to conceive the concept as if it were only a "mental representation" can lead to "representation" in a subjective sense (*Vorstellung*), when it seems more reasonable to think that the concept might be a "representation" in objective terms (*Darstellung*), i.e., something that it is not the reality in itself (*an sich*), but that possesses public character. Thus, it is neither genuinely subjective nor private, properly speaking.⁵⁹

⁵³ *Conceptual Revolutions* includes the analysis of the development of Copernicus' theory of the solar system, Newtonian mechanics, Lavoisier's oxygen theory, Darwin's theory of evolution, Einstein's theory of relativity, quantum mechanics, and the geological theory of plate tectonics. Nowadays Thagard's focus of attention is on neuroscience.

⁵⁴ Cf. *Conceptual Revolutions*, pp. 47-48.

⁵⁵ As usual, Thagard takes into account the first Kuhnian period. On "revolutions" in this approach, see KUHN, TH. S., *The Structure of Scientific Revolutions*, 2nd ed., pp. ix, 12, 48, 85-86, 90, 92-94, 102, 111, 121 and 167.

⁵⁶ Cf. THAGARD, P., *Conceptual Revolutions*, p. 50.

⁵⁷ Cf. *Conceptual Revolutions*, pp. 24-28.

⁵⁸ Cf. THAGARD, P., *Conceptual Revolutions*, p. 21.

⁵⁹ On the representation as *Vorstellung* and *Darstellung*, cf. GONZALEZ, W. J., *La Teoría de la Referencia. Strawson y la Filosofía Analítica*, Ediciones Universidad de Salamanca y Publicaciones de la Universidad de Murcia, Salamanca-Murcia, 1986, pp. 37-38.

Concepts cannot be reduced to mere “representations” — and, even less, to pure mental representations — because there are more elements involved in concepts. This issue of how to understand “concepts” raised a kind polemic with Sir Peter Strawson.⁶⁰ How they should be characterized is a very important issue for science, in general, and for cognitive sciences, in particular. On the one hand, the historicity of concepts is key in understanding the scientific change, either “evolutionary” or “revolutionary;” and, on the other, agents deal with the historically concrete through concepts, because their interaction with the changeable reality is carried out using concepts.

5. THE ROLE OF CONCEPTS AND THE NEXUS WITH WHAT IS HISTORICALLY CONCRETE

Science as a human activity involves the presence of a *dynamic* facet, which is not merely diachronic and accompanies the structural aspect of science. Dynamics can be seen in the individual actions of the scientists as well as in their social actions, which include complexity being grasped by concepts. Thus, this human activity — either individual or social — does not merely happen *in* time (the temporal character), because it varies and enriches *through* time. Hence, historicity has influence on the reality itself of human activity.⁶¹ In this regard, historicity can be noticed in science as *our activity*, because we can find aims, processes and results in science under the effects of the oscillations of historicity.

Usually, the cognitive approach emphasizes the role of the subject who makes science. If this criterion is assumed, then we need to go more deeply into the *conceptual scheme* of the researchers, those who are the subjects of scientific experiences. This analysis includes a relevant set of concepts related to history, time and change that have those agents that make science. In fact, we use historical terms to make the set of changes in aims, processes and results of science intelligible, both in basic research and in applied research. For several decades — at least, since the 1960s — in the philosophical studies there has been an insistence on the historical components of the language, knowledge and methods used by scientists. These case-studies in science have enjoyed wide recognition, because they seek to clarify the scientific change and its repercussion for scientific progress.⁶²

Historicity certainly affects the knowing subject, but it also concerns the known object (above all, if it is social or artificial). From a cognitive approach, the problem is to be focused from the concepts of agents that make science. The difficulty is then in harmonizing objectivity, a key feature for scientific activity, and historicity, which has repercussions in central elements of the research: a) the researcher (or group of researchers); b) the reality that is studied; and c) the interaction between both. The problem of Thagard’s viewpoint is that, in my judgment, it does not guarantee the *objectivity* of the concept itself.

⁶⁰ The origin of the polemic on “processes” and “concepts” is in my paper “P. F. Strawson’s Moderate Empiricism: The Philosophical Basis of his Approach in Theory of Knowledge,” published in *The Library of Living Philosophers*. In the same volume of 1998, Strawson published “Reply to Wenceslao J. Gonzalez.” Later on came my paper “El empirismo moderado en Filosofía Analítica: Una réplica a P. F. Strawson,” which was continued in a personal letter from the Oxford philosopher endorsing what I have published in that paper of 2003.

⁶¹ Cf. GONZALEZ, W. J., “Caracterización del objeto de la Ciencia de la Historia y bases de su configuración metodológica,” pp. 89, 101 and 103.

⁶² Cf. GONZALEZ, W. J., “Novelty and Continuity in Philosophy and Methodology of Science,” in GONZALEZ, W. J. and ALCOLEA, J. (eds.), *Contemporary Perspectives in Philosophy and Methodology of Science*, especially, pp. 3-4.

However, the same has happened to many analytical philosophers of empiricist inspiration and open to naturalism. Among them, with his own line of thought, is P. F. Strawson.⁶³ His notion of “concept” has shown some doses of eclecticism: sometimes he seems to accept the position of realism of common sense; but his preference goes to the Kantian viewpoint, where there are general concepts that are exemplified in a variety of particular cases.⁶⁴ He also establishes a clear link between theory of knowledge and theory of meaning, where both are couched with the idea of philosophy as a conceptual activity: “concepts of the real can mean nothing to the user of them except in so far as they relate, directly or indirectly, to possible experience of the real.”⁶⁵

Strawson relies on the *principle of significance*, which involves the need of empirical application for the concepts. According to that principle, “there can be no legitimate, or even meaningful, employment of ideas or concepts which does not relate them to empirical or experiential conditions of their application.”⁶⁶ Thus, in order to use a concept in a certain way, we should be able to specify the kind of experience-situation to which the concept, used in that way, would apply. This is what really envisages a legitimate use of that concept.⁶⁷

The historical aspects of “concepts,” which Strawson might consider, are relegated due to his detachment from the category of “process.”⁶⁸ But we should accept the *historicity* as an actual feature of human activity, which has to be included in concepts. This entails that concepts should be open to grasp the existing change in reality (i.e., the modification of concepts in order to generate a resemblance with real world). In other words, the acceptance of the objectivity in concepts requires incorporating the historicity of science, of the agents, and of the reality itself (above all, social and artificial).

Concerning this possibility of a nexus between objectivity and historicity, the first step is to accept that the notion of “concept” involves a genuine *resemblance* between the representation made by the knowing subject and the objective reality. Thus, it might be then — as Thagard recognizes — representations as mediators between the knowing subject and what is known. Here, in a certain way — as Strawson suggests — nothing is pure and simply “known,” because everything that is known is so by someone or for someone.⁶⁹ Hence, initially, when we are dealing with the knowing subject, the “concept” is something which accompanies what is “given.”⁷⁰ But even then the concept requires a specific content.

⁶³ Cf. GONZALEZ, W. J., “P. F. Strawson’s Moderate Empiricism: The Philosophical Basis of his Approach in Theory of Knowledge,” in HAHN, L. E. (ed.), *The Philosophy of P. F. Strawson*, The Library of Living Philosophers, Open Court, La Salle, IL, 1998, pp. 329-358.

⁶⁴ Cf. STRAWSON, P. F., *Subject and Predicate in Logic and Grammar*, Methuen, London, 1974, pp. 14-16.

⁶⁵ STRAWSON, P. F., *Analysis and Metaphysics*, Oxford University Press, Oxford, 1992, p. 52.

⁶⁶ STRAWSON, P. F., *The Bounds of Sense. An Essay on Kant’s Critique of Pure Reason*, Methuen, London, 1966, p. 16. Cf. STRAWSON, P. F., *Analysis and Metaphysics*, p. 52.

⁶⁷ Cf. *The Bounds of Sense*, p. 16. Cf. *Analysis and Metaphysics*, p. 52.

⁶⁸ The analysis of the category of “process” carried out in GONZALEZ, W. J., “El empirismo moderado en Filosofía Analítica: Una réplica a P. F. Strawson,” in FALGUERA, J. L., ZILHÃO, A. J. T., MARTÍNEZ, C. and SAGÜILLO, J. M. (eds.), *Palabras y pensamientos: Una mirada analítica / Palavras e Pensamentos: Uma perspectiva analítica*, Publicaciones Universidad de Santiago, Santiago de Compostela, 2003, pp. 207-237; especially, pp. 224-230.

⁶⁹ Cf. STRAWSON, P. F., “Does Knowledge have Foundations?,” *Teorema*, monographic issue on knowledge and belief, Valencia, 1974, p. 101.

⁷⁰ Cf. STRAWSON, P. F., “Perception and its Objects,” in MACDONALD, G. F. (ed.), *Perception and Identity*, Macmillan, London, 1979, p. 47.

There is a second step for connecting objectivity and historicity, which is central in any science. This includes the idea of exemplification, open to collection and distinction. Thus, a general concept, which is something very common in any scientific discipline, could be exemplified in a great number of different concrete instances. In this regard, concepts show two main features: (i) they are principles of collection, and (ii), they are principles of distinction.⁷¹ But this position, in order to be adequate for basic and applied sciences, requires a genuine intellectual possession of the reality. Moreover, the *concept* itself should be objective.

This entails that the concepts are more than mere “constructions” connected with spatial and temporal experience of bodies and persons. The objectivity of the *content* of the concept requires the possibility of achieving a genuine intellectual possession of the reality. Thus, “what exists in the concept and what exists in reality could be the same, but it is possessed in a different way: the intellectual concept can contain what physically exists in the world”⁷² (be it in the natural, social or artificial sphere).

Obviously, there is here a connection with the previous step. Because the concept appears as a mental representation insofar as it intervenes in a psychological act; but the concept itself — as content — is not constrained to that singular act of the subject. Thus, the concept is not reduced to a mere act of thought and it is not a Platonic entity, because the concept needs to be accessible to thinkers in general without generating a new world apart. On the one hand, this perspective avoids the restrictions that affect many empiricists in theory of knowledge and naturalists in epistemology;⁷³ and, on the other hand, this view does not fall into the excesses of Platonism and some rationalist ontologies.

To overcome an excessive presence of the subjective factors and to stress the objective in the content of the concept is crucial when we are dealing with historicity. In this regard, Strawson has focused on this point and taken into account my objections: “Now I certainly do not regard a concept as subjective in the sense in which a particular episode in the mental life of an individual is subjective. A concept must, as Gonzalez says, be accessible to thinkers in general, a shared or shareable possession. But, equally, a concept is not itself an object in nature, though objects in nature may fall under it. So far I think Professor Gonzalez and I are in complete agreement.”⁷⁴

Unquestionably, *historicity* can be a property of what is researched (of societies or artifacts, which lead to obsolescent); but it also can be present in the agents that research and in the science that is done. In addition, “historicity” is also a concept that allows us to grasp a universal that is exemplified in many cases (especially, social and artificial ones). Strawson has proposed the distinction between the *concept* and the *property* (the universal) of which it is a concept: “The property is certainly objective; and is so whether we conceive of it as *ante rem* or as *in rebus* (as instanced) or as both. And since the property is precisely the *content* of the concept, the concept is not at risk of lacking objective content. But still we must insist on the distinction between

⁷¹ Cf. STRAWSON, P. F., *Subject and Predicate in Logic and Grammar*, p. 17.

⁷² GONZALEZ, W. J., “P. F. Strawson’s Moderate Empiricism: The Philosophical Basis of his Approach in Theory of Knowledge,” in HAHN, L. E. (ed.), *The Philosophy of P. F. Strawson*, 1998, p. 350.

⁷³ In the case of Peter Strawson, he adopts a post-Kantian approach, embedded in Wittgensteinian suggestions. Thus, he offers a more realistic perspective to human knowledge than a vast majority of empiricists. Cf. GONZALEZ, W. J., “P. F. Strawson’s Moderate Empiricism: The Philosophical Basis of his Approach in Theory of Knowledge,” pp. 349-350.

⁷⁴ STRAWSON, P. F., “Reply to Wenceslao J. Gonzalez,” in HAHN, L. E. (ed.), *The Philosophy of P. F. Strawson*, The Library of Living Philosophers, p. 360.

concept and property — a distinction which becomes clear if we consider what it is, on the one hand, to possess (or exemplify) a property and what it is, on the other hand, to possess (or grasp) a concept.”⁷⁵

Peter Strawson also points out that “it is perfectly possible for someone, or something, to have a property and lack the concept of it; it is equally possible for someone to grasp the concept and lack the property. All things, of whatever category, animate, inanimate, or abstract, have properties; only conscious beings and cultures can be said to possess concepts. Concepts in this sense are mind-dependent, while properties (unless they are mental properties) are not; but this has no force to show that concept-possession falls in any way short of intellectual grasp of the objective realities which the concepts are concepts of.”⁷⁶

Through this characterization of a “concept” we can reach that, in science, the concept can be the intellectual possession of a property of the reality (natural, social or artificial). Thus, the objectivity in the content of the concept (either be on animated entity, unanimated one or abstract) might be possible. “What we get then — in my judgment — is similarity dissimilar: the actual property is intentionally grasped in the concept — which includes similarity — and the concept is not the property as such that can be found in the *extramental* reality (which involves a dissimilarity from the point of view of its ontological *status*).”⁷⁷

It should be emphasized that the human conceptual structure is also under the possibility of *conceptual innovation*. This phenomenon can be seen in diverse realms of knowledge, especially in the sphere of various sciences and, certainly, it is key for scientific progress. There is a difference with what happens to many authors of the cognitive approach, because it should be stressed that the human conceptual structure as well as the reality itself, whose conceptualization is searched for, cannot be outside the historical dimension. Thus, there has been a concern of many thinkers to make compatible the objectivity of the conceptual content and the property of the changeable character of reality (mainly, social and artificial). Among them are a large number of philosophers of science, who have tried to overcome the relativist positions through the articulation of objectivity and historicity.⁷⁸

6. CONSIDERATIONS ON THE PERSPECTIVES OF THE AUTHORS ANALYZED AND EVALUATION OF THEIR CONTRIBUTIONS

So far, the analysis made here has pointed to the differences between evolution and revolution as frameworks of conceptual changes, the existence of three successive levels of historicity in the realm of the cognitive approach (science, agents and the reality itself researched), and the relevance for conceptual change of the issues on the specificity of content and the role of the knowing subject. In addition, the reflection has gone in some depth into the change of the

⁷⁵ STRAWSON, P. F., “Reply to Wenceslao J. Gonzalez,” p. 360.

⁷⁶ “Reply to Wenceslao J. Gonzalez,” p. 360.

⁷⁷ GONZALEZ, W. J., “El empirismo moderado en Filosofía Analítica: Una réplica a P. F. Strawson,” p. 233.

⁷⁸ One of these cases is analyzed in detail in GONZALEZ, W. J., “La Filosofía de I. Lakatos, 25 años después: Del ‘giro histórico’ a la incidencia metodológica en Economía,” in GONZALEZ, W. J. (ed.), *La Filosofía de Imre Lakatos: Evaluación de sus propuestas*, UNED, Madrid, 2001, pp. 13-103; especially, pp. 16-22 and 34-42.

From a cognitive approach, a proposal for harmonization of objectivity and historicity in science is carried out in KITCHER, PH., *The Advancement of Science: Science without Legend, Objectivity without Illusions*, Oxford University Press, N. York, 1993.

cognitive content in terms of conceptual revolutions as well as the role of concepts while dealing with what is historically concrete.

In many ways, the analysis in these pages has emphasized the contributions of Herbert Simon. He is a key author in the trajectory of cognitivism and considers the problem of historicity in the science of economics. He does so very late in his intellectual trajectory, in 1998. Besides, the role of historicity was not among his lines of research. Simon wrote on this issue because I asked him explicitly to do so. His perspective pays attention to the levels of historicity second — agents — and third — the change in the actual environment — but, *sensu stricto*, he does not focus on the first level of analysis: the historicity of the concepts in science. In other papers, he has recognized the importance of the study of past, both for the acquisition of information and for the models of discovery. However, the mere fact that he wanted to reproduce those contents by the used of machines — computer programs each time more sophisticated — highlights that when he was dealing with some historical factors he was not thinking of in terms of historicity.

Nonetheless, Simon achieves several things through his proposal of economics as a historical science.⁷⁹ 1) With these reflections, he attains an enlargement of his usual thematic field, insofar as he incorporates new elements to his vision of the economic behavior (the behavioral model). It is a distinct position from behaviorism, due to elements such as the stress in the cognitive components of the agents. 2) His paper on *Economics as a Historical Science* constitutes a contribution, because it facilitates a better understanding of the diverse historical factors — endogenous and exogenous — that might have repercussion on economic prediction, mainly in the microeconomic area. 3) His position, although recognizing the need for elements of the dominant economic history (i.e., technological change, institutional context, etc.), includes a new element in his detachment from mainstream economics, insofar as it aspires to invariant laws of economic endeavor.

Yet, from the point of view philosophical-methodological, Simon's proposal on economics as a historical science should be examined in depth. Following this line of study, the main question lies underneath his conception: the proposal seems to remain more in tune with the idea of "temporality" rather than being in accordance with the notion of "historicity." Thus, in his position the idea of "behavior" prevails over the concept of "activity," which, in my judgment, engages better the reality of economic undertaking as a dynamic process.⁸⁰

Besides his insistence on behavior, there is in Simon a model of rationality that is *adaptive* and *evolutionary*. Meanwhile there are other authors who, when are dealing with the links between rationality and predictability, propose a thematic distinction of the rational and evolutionary spheres in the rational choice. This separation of levels is defended in the following way: while rationality has an important role in learning, it has not role at all regarding evolution. Thus, evolutionary models do not compete with the models of rational election, because they deal with different phenomena, even though they are related.⁸¹

⁷⁹ Cf. GONZALEZ, W. J., "Herbert A. Simon: Filósofo de la Ciencia y economista (1916-2001)," in GONZALEZ, W. J. (ed.), *Racionalidad, historicidad y predicción en Herbert A. Simon*, Netbiblo, A Coruña, 2003, p. 23.

⁸⁰ Cf. GONZALEZ, W. J., "Rationality in Economics and Scientific Predictions: A Critical Reconstruction of Bounded Rationality and its Role in Economic Predictions," *Poznan Studies in the Philosophy of the Sciences and the Humanities*, v. 61, (1997), pp. 205-232.

⁸¹ Cf. BICCHIERI, C., *Rationality and Coordination*, Cambridge University Press, Cambridge, 1993, p. xii.

Paul Thagard tries to do what Simon has not carried out: he works on the historicity of science as such. His analysis is made from the perspective of concepts and seeks to achieve what Kuhn certainly did not accomplish in his first period: to configure the rationality of scientific change.⁸² Thus, both in science, in general, and in each science, in particular, the replacement of concepts is performed through rational processes, although episodically they might be “revolutionaries.” Thagard has made some genuine contributions to the problem of conceptual revolutions: he introduces the dynamics of theories in terms of *transition* from one theory to another, he accepts rationality in scientific revolutions, and he tries to develop a cognitive model of explanation.⁸³

According to this view, scientific change is neither a mere incorporation of theories nor a Kuhnian supplantation of theories. In Thagard the dynamic relation of theories adopts a position on replacement of theories that avoids mere incorporation (the assumption that new theories must be consistent with established science) and criticizes the supplantation of theories in terms of Kuhn’s incommensurability.⁸⁴ Hence, rationality is defended as an element of revolutions: (i) the psychological account of conversion shows that it has little in common with scientific change; (ii) it is easy to see the limitations of the models of sociologists of science when they explain the development of science without treatment of rationality; and (iii) Kuhn’s latest analogy — in this third phase — between conceptual systems in science and translation of language is limited.⁸⁵ The problem of Thagard’s edifice, which is particularly relevant regarding level one of analysis, is its grounding: it is built upon concepts as “mental representations.”

Certainly, concepts are much more than mental representations, as Strawson has shown. They are principles of collection and also principles of distinction; they are related to the properties of the things, but they are not the properties themselves in ontological terms; etc. However, in his case, the failure is in the opposite pole of this relation: the acknowledgement of the ontological character of historicity, because the processes of things and agents look at a reality that is changeable. This is the reason why, in this text, there is an explicit attempt to harmonize the three levels involved: 1) the historicity of science (i.e., the conceptual change); 2) the historicity of agents, who made science in social contexts; and 3) the historicity of the reality itself studied (above all, social and artificial).

Habitually, neither the British empiricist tradition nor influential analytical philosophers, such as Ludwig Wittgenstein, have actually emphasized the human *historicity*. Thus, those modern thinkers and these contemporary authors did not stress, in general, the testable fact of the possession of a *historical character* on behalf of the human being. He or she is an individual reality which is also inserted in the environment of a society that is historic as well. This is an ontological aspect that has repercussions for the social sciences and the sciences of the artificial: human activity has, in effect, a *dynamic* facet — not merely diachronic — that accompanies other components, which are structural. And this facet is constitutive of individual actions as well as social actions. Hence, human activity — either individual or social — is not nor merely

⁸² As is well known, even in the first period of Kuhn the internal elements of science have more epistemological and methodological weight than the external factors.

⁸³ Cf. GONZALEZ, W. J., “Towards a New Framework for Revolutions in Science,” pp. 613-614.

⁸⁴ Cf. THAGARD, P., *Conceptual Revolutions*, pp. 104-107.

⁸⁵ Cf. *Conceptual Revolutions*, pp. 103 and 108-117.

something that happens in time, because it modifies and enriches *through time*: historicity has influenced the reality itself of human activity.⁸⁶

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⁸⁶ Cf. GONZALEZ, W. J., "El empirismo moderado en Filosofía Analítica: Una réplica a P. F. Strawson," p. 224.

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II

Cognitive Science and Conceptual Change

3. Conceptual Change in Cognitive Science: The Brain Revolution
4. Is Embodied Cognition a Good Conceptual Revolution?

CONCEPTUAL CHANGE IN COGNITIVE SCIENCE: THE BRAIN REVOLUTION

Paul Thagard

1. KUHN AND CONCEPTUAL CHANGE

The most cited philosopher of the twentieth century, according to Google Scholar, is not Russell, Wittgenstein, Carnap, Quine, Putnam, Rawls, Kripke, Husserl, Heidegger, or Foucault. Rather, by far the most frequently cited philosophical work is Thomas Kuhn's *The Structure of Scientific Revolutions*. First published in 1962 with a second edition in 1970, this book is widely read by scientists and other scholars in many fields, and yielded terms such as *paradigm shift* that have become part of widespread usage. When the book first appeared, many philosophers took it as a challenge not only to the logical positivist orthodoxy of the day, but also to any attempt to understand science as a rational investigation of the world. It seemed that the conceptual changes that Kuhn described in the history of science were so radical that they ruled out any possibility of science being progressively successful in describing how the world really is.

Other philosophers, however, took Kuhn's book as a challenge to articulate in fuller historical detail the nature of historical developments in science.¹ However, purely historical approaches lacked a vocabulary for describing the structure and growth of scientific knowledge due to abandonment of the aim of logical positivism to analyze scientific theories as structures in formal logic. Starting in the 1980s, however, this gap began to be filled by the introduction of ideas from cognitive psychology into the philosophy of science. Kuhn had made use of ideas from *Gestalt* psychology and early cognitive-psychological research on concepts, but ideas emerging from cognitive psychology and artificial intelligence provided a greatly enriched vocabulary for describing conceptual change.² These philosophical approaches complemented work by psychologists to understand conceptual change in ordinary people.³

¹ E.g. LAKATOS, I., "Falsification and the Methodology of Scientific Research Programs," in LAKATOS, I. and MUSGRAVE, A. (eds.), *Criticism and the Growth of Knowledge*, Cambridge University Press, Cambridge, 1970, pp. 91-195; and LAUDAN, L., *Progress and its Problems*, University of California Press, Berkeley, 1977.

² E.g. ANDERSEN, H., BARKER, P. and CHEN, X., *The Cognitive Structure of Scientific Revolutions*, Cambridge University Press, Cambridge, 2006; GIERE, R. N., *Explaining Science: A Cognitive Approach*, The University of Chicago Press, Chicago, 1988; GIERE, R. N. (ed.) *Cognitive Models of Science*, Vol. 15, *Minnesota Studies in the Philosophy of Science*, University of Minnesota Press, Minneapolis, 1992; GIERE, R. N., "The Cognitive Structure of Scientific Theories," *Philosophy of Science*, v. 61, (1994), pp. 276-296; NERSESSIAN, N. J., "How Do Scientists Think? Capturing the Dynamics of Conceptual Change in Science," in GIERE, R. N. (ed.), *Cognitive Models of Science*, pp. 3-44; NERSESSIAN, N. J., *Creating Scientific Concepts*, The MIT Press, Cambridge, MA, 2008; THAGARD, P., *Conceptual Revolutions*, Princeton University Press, Princeton, 1992; and THAGARD, P., *How Scientists Explain Disease*, Princeton University Press, Princeton, 1999.

³ Cf. CAREY, S., *Conceptual Change in Childhood*, The MIT Press/Bradford Books, Cambridge, MA, 1985, and CHI, M. T. H., "Three Types of Conceptual Change: Belief Revision, Mental Model Transformation, and Categorical Shift," in VOSNIADOU, S. (ed.), *International Handbook of Research in Conceptual Change*, Routledge, New York, 2008, pp. 61-82.

My aim in this paper is not to defend the cognitive-historical approach to understanding science, or to argue that it allows philosophy to maintain some of Kuhn's insights into the complexity of conceptual change while avoiding his relativistic conclusions. Rather, I want to apply the cognitive-historical approach to a major current development in cognitive science itself, originating from the ascendancy of neural explanations in all areas of psychology, including social, clinical, developmental, and organizational psychology as well as cognitive. I call this development the Brain Revolution.⁴ This paper will describe the conceptual changes now underway in psychology, and discuss their philosophical implications. A companion piece examines the consequences of the Brain Revolution for psychiatry and related areas of medicine.⁵

2. THE COGNITIVE REVOLUTION

Cognitive psychology arose in the 1950s and 1960s in reaction to behaviorist approaches that had been dominant in many circles for decades. Influenced by positivism, behaviorists rejected the postulation of internal mental states as non-scientific, and instead preferred explanations that fit with the following explanation schema:

Behaviorist Explanation Schema:

Explanation target: Why do animals, including people, have a particular kind of **behavior**?

Explanatory pattern:

Animals are subject to **stimuli** from their environments.

Because of reward-based learning mechanisms, animals develop **stimulus-response** patterns.

These **stimulus-response** patterns produce observed **behavior**.

By the 1950s, however, it was becoming evident that such explanations, restricted to observable environments and behavior, were inadequate to explain even simple animal behaviors such as maze running, let alone complex kinds of human thinking such as language use.

Through the experimental and theoretical work of researchers such as George Miller, Ulric Neisser, and Herbert Simon, an alternative way of explaining behavior arose, heavily influenced by the development in the 1950s of the first computers and computer languages.⁶ Computation provided a non-mystical way of understanding mental states as analogous to the data structures and algorithms that constitute computer programs. The result generated many ways of understanding thinking as a kind of information processing, in accord with the following schema:

Cognitive Explanation Schema:

Explanation target: Why do people have a particular kind of **intelligent behavior**?

⁴ Cf. THAGARD, P., *The Brain and the Meaning of Life*, Princeton University Press, Princeton, NJ, 2010.

⁵ See THAGARD, P. and FINDLAY, S., "Conceptual Change in Medicine: Explaining Mental Illness," in GONZALEZ, W. J. (ed.), *Conceptual Revolutions: From Cognitive Science to Medicine*, Netbiblo, A Coruña, 2011, pp. 157-177.

⁶ Cf. MILLER, G. A., "The Magical Number Seven, Plus or Minus Two: Some Limits on Our Capacity for Processing Information," *Psychological Review*, v. 63, (1956), pp. 81-97; NEISSER, U., *Cognitive Psychology*, Appleton-Century-Crofts, New York, 1967; and NEWELL, A. and SIMON, H. A., *Human Problem Solving*, Prentice-Hall, Englewood Cliffs, NJ, 1972.

Explanatory pattern:

People have mental **representations**.

People have algorithmic **processes** that operate on those **representations**.

The **processes**, applied to the **representations**, produce the **behavior**.

Textbooks in cognitive psychology attest to the success of this explanation schema for making sense of a large range of psychological phenomena such as perception, memory, learning, and problem solving. The so-called Cognitive Revolution was not a stark rejection of behaviorist ideas, because stimulus-response explanations remain useful for some behavioral patterns, especially in simple organisms.

Nevertheless, the developments in psychology in the 1950s and 1960s were revolutionary in two respects. First, the advent of cognitive psychology involved a rejection of behaviorist assumptions that *all* behavior in humans and other animals could be explained in terms of stimulus-response patterns. In contrast, cognitive psychologists contended that explanations of observed behavior required postulating mental representations along with computational procedures that operate on them. Second, concomitantly, the cognitive revolution introduced a new way of thinking of mental states and processes. In contrast to behaviorists who rejected the existence of mental states as unobservable and therefore unscientific, cognitive psychologists exploited the newly available analogy of computer programs to postulate that thinking is information processing. Then mental states are reclassified as information-processing states, in contrast to behaviorist assumptions that they are nothing and to commonsense assumptions that they are states of the non-material soul. Much contemporary philosophy assumes that mental states such as beliefs and desires are propositional attitudes, but this view is also incompatible with scientific evidence that supports alternatives to transcendental understanding of propositions.⁷

3. THE BRAIN REVOLUTION IN PSYCHOLOGY

Increasingly, however, it has become common for cognitive psychologists to develop explanations that are couched, not in abstract information-processing terms, but in terms of neural structures and processes. The reasons for this shift are both experimental and theoretical. During the 1990s, cognitive psychologists rapidly adopted newly developed technologies such as functional magnetic resonance imaging (fMRI) that make possible observations of brain activity through measurement of blood flow to areas of the brain involved in cognitive tasks. Complementing this experimental shift toward brain measurement was the theoretical development of new ways of understanding psychological processes, not in terms of the data structures and algorithms of computer science, but in terms of parallel processing of simple units akin to neurons. 1980s-style connectionism is giving way to the field of theoretical neuroscience, which develops more biologically realistic accounts of how brains perform cognition.⁸

⁷ See THAGARD, P., "How Cognition Meets Emotion: Beliefs, Desires, and Feelings as Neural Activity," in BRUN, G., DOGUOGLU, U. and KUENZLE, D. (eds.), *Epistemology and Emotions*, Ashgate, Aldershot, 2008, pp. 167-184; and THAGARD, P., *The Brain and the Meaning of Life*, *passim*.

⁸ Cf. CHURCHLAND, P. S. and SEJNOWSKI, T., *The Computational Brain*, The MIT Press, Cambridge, MA, 1992; DAYAN, P. and ABBOTT, L. F., *Theoretical Neuroscience: Computational and Mathematical Modeling of Neural Systems*, The MIT Press, Cambridge, MA, 2001; ELIASMITH, CH. and ANDERSON, C. H., *Neural Engineering: Computation, Representation and Dynamics in Neurobiological Systems*, The MIT Press, Cambridge, MA, 2003; O'REILLY, R. C. and MUNAKATA, Y., *Computational Explorations in Cognitive Neuroscience*, The MIT Press, Cambridge, MA, 2000; and THAGARD, P., *The Brain and the Meaning of Life*, *passim*.

The new developments employ something like the following explanation schema:

Neuroscience explanation schema:

Explanation target:

How does the brain carry out functions such as **cognitive tasks**?

Explanatory pattern:

The brain has **neurons** organized by synaptic connections into populations and brain areas.

The **neural populations** have spiking patterns that are transformed via sensory inputs and the spiking patterns of other neural populations.

Interactions of neural populations carry out functions including **cognitive tasks**.

New cognitive psychology textbooks such as Smith and Kosslyn integrate such neural explanations with traditional information-processing discussions of the results of psychological experiments.⁹ Using Kuhnian terminology, Smith and Kosslyn remark that there has been a shift in the paradigm way of viewing cognition.¹⁰ The newest editions of other cognitive psychology texts such as Anderson also increasingly employ ideas from cognitive neuroscience.¹¹

Thus what I have been calling the Brain Revolution is akin to the Cognitive Revolution in that it does not require a wholesale rejection of previous ideas, as occurred in such major scientific revolutions as the replacement of the phlogiston theory of combustion by Lavoisier's oxygen theory, or the replacement of creation theory by Darwin's theory of evolution by natural selection.¹² Nevertheless, the Brain Revolution does involve a substantial shift in the way that cognitive psychologists explain normal mental functioning, as I will now illustrate by describing a shift in the important theoretical notion of a concept.

In ordinary language, a concept is some sort of idea in the mind, but experimental results have led psychologists to develop different theories about what concepts are.¹³ From a behaviorist perspective, concepts are just fictions, because they cannot be directly observed. However, cognitive psychology is more in tune with a realist philosophy of science, according to which it is legitimate to postulate the existence of non-observable entities if they are required by explanatory hypotheses that are part of the best explanation of the available evidence. On the information-processing view of mental representation that dominated psychology from the 1960s through the 1990s, concepts are akin to the data structures that are part of every computer program.

But what kind of data structures are they? In the 1970s, psychologists rejected the classical notion of concepts as definable by necessary and sufficient conditions, and shifted to viewing concepts as prototypes that express only typical features of a class of things. The prototype theory, however, has been challenged by findings that support alternative views of concepts as sets of exemplars or as theory-like rules. There is currently no generally accepted psychological theory of concepts.

⁹ Cf. SMITH, E. E. and KOSSLYN, S. M., *Cognitive Psychology: Mind and Brain*, Pearson Prentice Hall, Upper Saddle River, NJ, 2007.

¹⁰ Cf. SMITH, E. E. and KOSSLYN, S. M., *Cognitive Psychology: Mind and Brain*, p. xi.

¹¹ See ANDERSON, J. R., *Cognitive Psychology and its Implications*, 7th ed., Worth, New York, 2010.

¹² Cf. THAGARD, P., *Conceptual Revolutions*, *passim*.

¹³ Cf. MURPHY, G. L., *The Big Book of Concepts*, The MIT Press, Cambridge, MA, 2002.

It now seems possible, however, to begin to resolve debates about the nature of concepts by developing theories in line with the Neuroscience Explanation Schema presented above. From this perspective, concepts are spiking patterns in neural populations. One of the major advantages of this shift is that it can accommodate all the previously competing views of what concepts are, since depending on circumstances neural patterns can implement classical definitions, prototypes, sets of exemplars, and rule-like theories.¹⁴ What appear to be competing theories about the nature of concepts may actually just be emphases on different aspects of concepts that can be reconciled by a common neurophysiological account of concepts as patterns of brain activation.

We thus have underway a major kind of conceptual change that involves reclassification, when a category is shifted from one branch of a taxonomic tree to another. Such reclassification is common in scientific revolutions, for example when Darwin reclassified humans as a kind of animal. The concept of a concept is shifting away from treating concepts as a kind of information processing abstraction towards viewing them as a kind of neural pattern. One of the main theoretical benefits of this shift is evidence acquired from brain scanning that suggests that concepts are not purely verbal structures, as many philosophers have assumed, but have aspects tied to many sensory modalities, especially vision. Brain scans show that concepts such as *car* can involve activity in many brain areas, for example visual areas that are related to perceptions of cars.¹⁵ Thus part of a concept can be activation of mental images that include not only what a car looks like, but how it sounds, smells, and perhaps even how it feels to the touch. The neural approach, taking concepts to be patterns of activation in multiple brain areas, can accommodate these findings in a way hard to do with the traditional information-processing account of concepts.

Machery draws an unfortunate inference from the apparent disarray in psychological theories of concepts.¹⁶ He rightly observes that there currently are a proliferation of theories of concepts, including prototype theories, exemplar theories, theory theories, and neo-empiricist theories, and concludes that cognitive science and philosophy might be better off to do without concepts altogether. In contrast, I have argued that all of these approaches to concepts can be assimilated within the neuroscience view that concepts are patterns of activity in neural networks.¹⁷ Hence there is no need to eliminate concepts from the ontology of cognitive science as long as they can be reclassified to be understood neurologically rather than as information processing structures or Platonic entities. Rule-based explanations of how cognitive information processing are also being rethought in relation to findings from brain scanning, taking into account the neural areas involved in problem solving using rules.¹⁸

Thus cognitive psychology seems currently to be undergoing an important kind of conceptual change involving the concept of mental representation, including the basic notion of what a concept is. Even more controversially, I think that a similar development is occurring in the understanding of emotions. Thagard and Aubie propose that emotions are complex patterns of

¹⁴ Cf. THAGARD, P., *The Brain and the Meaning of Life*, *passim*.

¹⁵ Cf. BARSALOU, L. W., SIMMONS, W. K., BARBEY, A. K. and WILSON, C. D., "Grounding Conceptual Knowledge in Modality-Specific Systems," *Trends in Cognitive Sciences*, v. 7, (2003), pp. 84-91.

¹⁶ Cf. MACHERY, E., *Doing without Concepts*, Oxford University Press, Oxford, 2009.

¹⁷ Cf. THAGARD, P., *The Brain and the Meaning of Life*, ch. 4.

¹⁸ Cf. ANDERSON, J. R., *How Can the Mind Occur in the Physical Universe?*, Oxford University Press, Oxford, 2007.

neural activity that integrate cognitive appraisals concerning the relevance the current situation to an agent's goals with perceptions of internal physiological states.¹⁹ They develop a neural model that combines the main philosophical and psychological competing theories of emotions, which traditionally has viewed them as either judgments *or* bodily perceptions. Thagard and Aubie's EMOCON model synthesizes cognitive appraisal and physiological perception as both part of the parallel activity of the brain. The result not only explains a wide range of psychological evidence about emotion, but also to satisfies philosophical worries about the nature of conscious emotional experience.²⁰ If this approach is correct, then emotions can be part of a scientific account of how the mind works, and not rejected as a useless idea that does not constitute a natural kind.

The Brain Revolution is even more radical than reclassifying mental states as brain states, because it makes the more revisionary claim that mental states are brain *processes*. Having a concept or belief or emotion is not just a state of the brain, but rather a pattern of neural firing that occurs over time. This change is analogous to other major changes in the history of science that involve shifts from states to processes, such as the jump away from thinking of heat as a state consisting of the substance choleric towards thinking of heat as a process of movement of molecules. This shift from commonsense ideas about mental states to scientific ideas about brain processes is another reason why the Brain Revolution is difficult for many people to fathom.

So far, I have described the kinds of conceptual change that are involved in reclassifying mental states and processes as brain processes, but I have not provided any grounds for justifying such reclassification. According to my account of conceptual revolutions, conceptual change is the result of major belief revisions that are made because a new theory has greater explanatory coherence than a previously accepted theory.²¹ I will not try here to summarize all the evidence that supports the brain revolution, which includes the increasing availability of neural explanations of cognitive phenomena such as perception, memory, inference, emotion, and even consciousness.²² Instead I want to review an additional source of evidence that is often ignored: the psychological effects of a wide variety of pharmaceuticals.

4. YOUR BRAIN ON DRUGS

If you have a glass of wine and feel relaxed, or a cup of coffee and feel alert, then you have altered your mental state by changing your brain chemistry. Alcohol affects activity of such neurotransmitters as glutamate, GABA, and dopamine; caffeine blocks the action of the neurotransmitter adenosine. Such changes are studied in the field of psychopharmacology, which concerns the effects of drugs on the mind and brain. This field investigates both recreational drugs such as alcohol, caffeine, marijuana, cocaine, and LSD, and therapeutic drugs such as antidepressants and antipsychotics. The aim of this section is to explore the implications of psychopharmacology for the explanation of psychological states.

¹⁹ See THAGARD, P. and AUBIE, B., "Emotional Consciousness: A Neural Model of How Cognitive Appraisal and Somatic Perception Interact to Produce Qualitative Experience," *Consciousness and Cognition*, v. 17, (2008), pp. 811-834.

²⁰ Cf. THAGARD, P., *The Brain and the Meaning of Life*, *passim*.

²¹ Cf. THAGARD, P., *Conceptual Revolutions*, *passim*.

²² Cf. SMITH, E. E. and KOSSLYN, S. M., *Cognitive Psychology*, *passim*; and THAGARD, P., *The Brain and the Meaning of Life*, *passim*.

A process is a structured sequence of successive stages or phases.²³ This concept is rather vague and hard to map on to current work in neuroscience. In contrast, neuroscientists frequently describe their investigations as involving the identification of neural mechanisms. A mechanism is a system of components whose properties, relations, and interactions produce regular changes.²⁴ Mechanisms explain processes by showing how interactions between components produce a sequence of stages. Hence to explain a mental process, we first identify a sequence of mental events such as thoughts, perceptions, and feeling, and then describe a mechanism whose interacting components produce that sequence. Most current scientific explanations of mental processes operate either at the cognitive level, where the components are mental representations such as rules or concepts, or at the neural level where the components are neurons. Researchers at both of these levels have had substantial explanatory successes, but psychopharmacology shows the need to consider mechanisms at the molecular level as well.²⁵

In order to explain the mental effects of recreational and therapeutic drugs, it is crucial to consider the mechanisms by which drugs can alter how one neuron influences another. (This influence occurs when a neuron produces and releases chemicals that cross the synaptic gap to another neuron and bind with its receptors.) Meyer and Quenzer list 11 ways in which drugs can enhance or interfere with the operation of synapses, and Leonard describes 20.²⁶ Here are some of the more important:

1. A drug can inhibit the synthesis of a neurotransmitter.
2. A drug can stimulate or inhibit the release of a neurotransmitter.
3. A drug can stimulate or block postsynaptic receptors.
4. A drug can inhibit degradation or reuptake of a neurotransmitter.

Even this short list makes it apparent that neurotransmitters and receptors are crucial components in understanding how drugs affect mental processes. More than 100 different neurotransmitters have been identified, and many of these have multiple kinds of corresponding receptors. For example, there are at least 11 different receptors for glutamate, the major chemical involved in excitatory transmission between neurons; and there are at least 3 for GABA, the main chemical for inhibitory transmission. Similarly, there are 5 main subtypes of dopamine receptors, and at least 15 main subtypes of serotonin receptors. Because different drugs can enhance or inhibit the effects of neurotransmitters at different receptors, psychopharmacology has to pay attention to the variety of receptors as well as the variety of neurotransmitters. I will illustrate the complexity of these effects by reviewing the effects of two recreational drugs — alcohol and LSD — and one therapeutic drug, chlorpromazine.

²³ Cf. RESCHER, N., *Process Philosophy* 2002. Available from <http://plato.stanford.edu/archives/sum2002/entries/process-philosophy> (access on June 25, 2007).

²⁴ See, for example SALMON, W., *Scientific Explanation and the Causal Structure of the World*, Princeton University Press, Princeton, 1984; BECHTEL, W. and RICHARDSON, R. C., *Discovering Complexity*, Princeton University Press, Princeton, 1993; MACHAMER, P. K., DARDEN, L. and CRAVER, C. F., "Thinking about Mechanisms," *Philosophy of Science*, v. 67, (2000), pp. 1-25; and BECHTEL, W. and ABRAHAMSEN, A. A., "Explanation: A Mechanistic Alternative," *Studies in History and Philosophy of Biology and Biomedical Sciences*, v. 36, (2005), pp. 421-441.

²⁵ Cf. THAGARD, P., *Hot Thought: Mechanisms and Applications of Emotional Cognition*, The MIT Press, Cambridge, MA, 2006.

²⁶ See MEYER, J. S. and QUENZER, L. F., *Psychopharmacology: Drugs, the Brain, and Behavior*, Sinauer Associates, Sunderland, MA, 2005; and LEONARD, B. E., *Fundamentals of Pharmacology*, 2nd ed., John Wiley, Chichester, 1997.

Many people are familiar with the effects that alcohol can have on their mental processes, but not with the neurochemical mechanisms that produce these changes. According to Meyer and Quenzer, alcohol has major effects on glutamate, GABA, dopamine, and opioid systems.²⁷ Glutamate has receptors on many cells in the central nervous system, and alcohol has its greatest effect on the NMDA receptor. Alcohol reduces the effectiveness of glutamate at the NMDA receptor, which is crucial for learning and memory via long-term potentiation. This inhibition of glutamate transmission explains the memory loss sometimes associated with intoxication. In addition, alcohol binds to the GABA_A receptor complex, just like sedatives and anti-anxiety drugs such as Valium. This binding allows chloride ions to enter the postsynaptic neuron, facilitating the inhibitory response that GABA normally produces and thereby decreasing anxiety. The pleasurable effects of alcohol are the result of it increasing the firing rate of dopaminergic neurons in the ventral tegmental area, elevating the amounts of dopamine released in the nucleus accumbens, the brain's major pleasure center. There is some evidence that a particular dopamine receptor gene, D2, may be associated with excessive alcohol consumption.²⁸ Finally, the mental effects of alcohol may result in part from their effects on endogenous opioid activity, including increasing endorphin release. Opioid receptor antagonists such as naloxone reduce alcohol self-administration in animals. According to Diamond and Gordon, alcohol also affects other neurotransmitters such as serotonin.²⁹ There is thus ample evidence that the mental process of intoxication is also a brain process, but one whose understanding requires attention to the molecular mechanisms of neurotransmission.

Similar attention is crucial for understanding the effects of LSD. Lysergic acid diethylamide (LSD-25) is a semisynthetic substance with a molecular structure built on the same tryptamine structure as 5-hydroxytryptamine (5-HT; serotonin).³⁰ As reviewed by Nichols, it has been known since the 1950's that LSD affects serotonin systems in the brain with recent evidence pinpointing stimulation of excitatory 5-HT_{2A} receptors that are common in the neocortex, frontal cortex, parietal cortex and reticular thalamic nucleus.³¹ Serotonergic projections predominate from the raphé nucleus into areas of the cortex and thalamus. The mechanisms behind hallucinations are still speculative but insights into the thalamus and its role in hallucinations have shed some light on them.³²

LSD molecules work to inhibit serotonergic projections from the raphé nucleus to other brain areas. Serotonin plays a key role in inhibiting activity in various regions of the brain including the prefrontal cortex and the thalamus. Serotonin molecules bind to 5-HT_{2A} receptors on GABAergic neurons that cause the GABAergic neuron to generate action potentials. This excitation directly inhibits surrounding neurons by releasing the neurotransmitter GABA. This inhibition is crucial for gating mechanisms in the thalamus and for selective attention

²⁷ Cf. MEYER, J. S. and QUENZER, L. F., *Psychopharmacology*, *passim*.

²⁸ See PREUSS, U. W., ZILL P., KOLLER G., BONDY B. and SOKYA, M., "D2 Dopamine Receptor Gene Haplotypes and their Influence on Alcohol and Tobacco Consumption Magnitude in Alcohol-dependent Individuals," *Alcohol and Alcoholism*, v. 42, (2007), pp. 258-266.

²⁹ Cf. DIAMOND, I. and GORDON, A. S., "Cellular and Molecular Neuroscience of Alcoholism," *Physiological Reviews*, v. 77, n. 1, (1997), pp. 1-20.

³⁰ Cf. NICHOLS, D. E., "Hallucinogens," *Pharmacology and Therapeutics*, v. 101, (2004), pp. 131-181.

³¹ Cf. NICHOLS, D. E., "Hallucinogens," pp. 131-181.

³² Cf. SHERMAN, S. M. and GUILLERY, R. W., *Exploring the Thalamus and its Role in Cortical Function*, 2nd ed., The MIT Press, Cambridge, MA, 2006.

in the prefrontal cortex.³³ When LSD acts to reduce the amount of serotonin in these brain areas, the GABAergic neurons are not excited, and hence fail to inhibit the neurons around them. In the thalamus, this reduction of modulation can cause an overabundance of sensory information to enter the cortex. When such excess of stimulation combines with undermodulation of the locus ceruleus, which contributes to novelty detection, everything around a person can seem extraordinary.³⁴

Hallucinations are hypothesized to occur as a result of an underconstrained thalamus.³⁵ Normally, afferent sensory information from the body and internal representations from memories or prediction mechanisms are modulated by the reticular thalamus with GABAergic neurons that are activated by serotonin on the 5-HT_{2A} receptors.³⁶ When LSD decreases serotonin levels, internal representations are able to create a stronger presence in thalamic nuclei that can be experienced as sensory hallucinations. The thalamocortical pathways can interact with the same thalamic nuclei as sensory pathways, producing the same internal state regardless of the sensory signal's origin. When we dream, afferent sensory signals are cut off and internal representations are able to take over. Hallucinations can be thought of as wakeful dreaming, because in both cases the prefrontal cortex supplies the sensory information that is consciously experienced. Because the hallucinated representations end up looking like actual sensory signals in the thalamus, they are experienced as being very real. It is not a matter of incorrectly interpreting signals in the brain, as both real and hallucinated experiences are represented the same way.

Hallucinations are also experienced by people with schizophrenia, which can be treated with drugs whose understanding requires attention to the molecular level. The first successful anti-psychotic drug was chlorpromazine, commercially known as Thorazine, which was discovered and widely adopted in the 1950s. Schizophrenia is a common disorder, afflicting around 1% of the population with severe distortions of perception, thought, emotion, and motor behavior. Chlorpromazine is often effective in reducing hallucinations, delusions, and disordered thinking in people with schizophrenia, although it can also have severe side effects.

Research suggests that the main mechanism of action of chlorpromazine and related drugs is binding to dopamine receptors, which reduces the excessive dopaminergic transmission thought to be responsible for hallucinations and related thought disorders. One kind of dopamine receptor, D₂, seems to be particularly important for the effectiveness of anti-psychotics, although other dopamine, serotonin, and norepinephrine receptors are also affected. Hence to explain the disordered thinking in people with schizophrenia, we need to consider a molecular mechanism that allows chlorpromazine to reduce dopaminergic transmission by blocking D₂ receptors. The mental process of hallucinating in schizophrenics can legitimately be identified with a brain process produced by a mechanism that includes the operation of the neurotransmitter dopamine and its receptors. (As we saw earlier, hallucinations can also be caused by LSD and other drugs that affect serotonin receptors.) Different mental disorders treated with drugs such as antidepressants can also be viewed as brain processes, as long as the underlying mechanisms are understood in molecular as well as neural terms.

³³ Cf. SHERMAN, S. M. and GUILLERY, R. W., *Exploring the Thalamus and its Role in Cortical Function*, *passim*.

³⁴ Cf. NICHOLS, D. E., "Hallucinogens," pp. 131-181.

³⁵ Cf. BEHRENDT, R. and YOUNG, C., "Hallucinations in Schizophrenia, Sensory Impairment, and Brain Disease: A Unifying Model," *Behavioral and Brain Sciences*, v. 27, (2005), pp. 771-830.

³⁶ Cf. SHERMAN, S. M. and GUILLERY, R. W., *Exploring the Thalamus and its Role in Cortical Function*, 2nd ed., *passim*.

I concisely summarize some of the main results of psychopharmacology in two tables. Table 1 displays some of what is known about the neural mechanisms responsible for the psychological effects of various recreational drugs. Table 2 summarizes the neural mechanisms of important classes of drugs used to treat mental illnesses. The complete neural mechanisms by which these drugs operate are vastly more complex than tables 1 and 2 suggest. For example, there is evidence that antidepressants do not improve mood immediately by increasing levels of serotonin, but rather over a period of a few weeks by encouraging growth of new neurons.³⁷

Table 1. Neural mechanisms by which recreational drugs produce psychological effects.

<i>Drug</i>	<i>Mechanisms</i>	<i>Psychological effect</i>
alcohol	increase dopamine, GABA; reduce glutamate	relaxation, less inhibition
caffeine	block adenosine, increase dopamine	alertness, edginess
nicotine	increase acetylcholine	stimulation, relaxation
cocaine, amphetamines	increase dopamine, serotonin, norepinephrine	excitement, euphoria
marijuana	block anandamine	relaxation
heroin	increase dopamine, stimulate opioid receptors	euphoria
LSD, mescaline	stimulate serotonin receptors	hallucinations

Table 2. Some of the neural mechanisms and psychological effects of important classes of therapeutic drugs.

<i>Drug Class</i>	<i>Neural Mechanism</i>	<i>Psychological effect</i>
antianxiety, e.g. Valium, Xanax	increase GABA	relaxation
antidepressant, e.g. Prozac, Zoloft	increase serotonin, dopamine	decrease depression
antipsychotic, e.g. Thorazine	block dopamine	reduce hallucinations
L-dopa	increase dopamine	improve motor control

³⁷ See GOULD, E., "Serotonin and Hippocampal Neurogenesis," *Neuropsychopharmacology*, v. 21, (1999), pp. 46S-51S.

5. NEUROCHEMICAL AND OTHER MECHANISMS

It should be clear that the neurochemical explanations of the psychological effects of drugs go beyond the neuroscience explanation schema presented earlier, which was restricted to how neural populations can successfully carry out cognitive tasks. The disruption of cognitive functioning by drugs requires a different explanation schema:

Neurochemical explanation schema:

Explanation target:

How are **cognitive functions** altered by **drugs**?

Explanatory pattern:

The brain has **neurons** organized by **synaptic connections** into populations and brain areas.

Synaptic connections depend on **neurotransmitters** that carry information between neurons.

Disruption of **neurotransmitters** by **drugs** alters **cognitive functions**.

This schema fits all the explanations of the effects of drugs, both therapeutic and recreational, given in the previous section. Different neuroscientific explanation schemas are required for the explanation of mental illness.³⁸

The fecundity of neurochemical explanations of the psychological effects of drugs provides strong evidence for the revolutionary claim that mental processes are neurological processes, rather than purely computational ones (as proposed by the information-processing view of mind introduced by the initial cognitive revolution) or supernatural ones (as assumed by many ordinary people and traditional philosophers). If thinking is a neural process that we know to be chemical as well as electrical, then it is easy to see how chemical disruptions can cause changes in mental states. Hence consideration of psychopharmacology provides a useful supplement to neuropsychological explanations of cognitive functioning.

However, I emphatically do not want to suggest that the brain revolution requires that all explanations of human behavior operate only at the neurochemical level. I have argued elsewhere that there are four hierarchically related kinds of mechanism relevant to understanding mental phenomena, operating at social, cognitive, neural, and molecular levels.³⁹ Table 3 sketches the constituents of those mental mechanisms. On this view, explanation in the cognitive sciences is inherently multilevel, so that explanations of complex behaviors can legitimately draw, not just on biochemical mechanisms such as how drugs affect neurotransmitters, but on a full range of neural, cognitive, and even social mechanisms. A major source of causes of why people behave as they do is their social context: interactions with other people produce changes at all other levels. For example, if someone insults you, then you undergo changes that range from the psychological (you are thinking about revenge) to the chemical (your level of the stress hormone cortisol goes up). The brain revolution is not ruthlessly reductionist and retains room for social and psychological explanations as long as these mesh with underlying neural and chemical mechanisms.

³⁸ Cf. THAGARD, P. and FINDLAY, S., "Conceptual Change in Medicine: Explaining Mental Illness," pp. 157-177.

³⁹ See THAGARD, P., *Hot Thought: Mechanisms and Applications of Emotional Cognition, passim*; and THAGARD, P., *The Brain and the Meaning of Life, passim*.

Table 3. Constituents of mental mechanisms.⁴⁰

<i>Level</i>	<i>Components</i>	<i>Relations</i>	<i>Interactions</i>	<i>Changes</i>
Social	Persons and social groups	Association, membership	Communication	Influence, group decisions
Cognitive	Mental representations such as concepts	Constituents, associations, implication	Computational processes	Inferences
Neural	Neurons, neural groups	Synaptic connections	Excitation, inhibition	Brain activity
Molecular (biochemical)	Molecules such as neurotransmitters and proteins	Constituents, physical connection	Biochemical reactions	Transformation of molecules

6. CONCLUSION

Conceptual revolutions bring new concepts, new conceptual organization, new hypotheses, and new explanation schemas. Often they depend on novel evidence achieved via new instruments: the Copernican revolution grew out the availability of the telescope, and the medical revolution brought about by Pasteur's germ theory grew out of the availability of the microscope. Similarly, the Brain Revolution has required new evidence resulting from new tools for scanning brain processes, especially machines that perform functional magnetic resonance imaging. Moreover, the Brain Revolution has introduced new concepts such as *neural firing pattern*, new conceptual organizations such as reclassifying mental states as brain states, new hypotheses such as that emotion is a brain process, and new neural and neurochemical explanation schemas. I have described some of the conceptual changes now taking place in cognitive psychology as it increasingly becomes incorporated with cognitive neuroscience; similar developments are occurring in social, developmental, and clinical psychology. This incorporation hardly amounts to reduction in the classic philosophical sense, but is highly interactive, as many ideas from cognitive psychology have influenced the kinds of experiments done by researchers in neuroscience.

Unlike the Copernican and Pasteur revolutions, the Brain Revolution no dramatic replacement of old scientific theories by new ones, but rather a slow modification of psychological hypotheses and explanations as new theoretical ideas emerge in neuroscience. Starting in the late 1980s and accelerating rapidly in the 1990s, psychologists have been able to observe brain functioning non-invasively, providing masses of evidence that support current neurocomputational explanations of psychological processes. The Brain Revolution is just beginning.⁴¹

⁴⁰ From THAGARD, P., *Hot Thought: Mechanisms and Applications of Emotional Cognition*, p. 6.

⁴¹ Acknowledgements. Thanks to Brand on Aubie for research assistance on hallucinations, and to the Natural Sciences and Engineering Research Council of Canada for funding.

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IS EMBODIED COGNITION A GOOD CONCEPTUAL REVOLUTION?

Pascual F. Martínez-Freire

1. A GOOD START: NOTION OF COGNITION

It may be surprising — and indeed some persons are surprised — the employment of the word “cognition,” which is seldom used, instead of the word “knowledge,” which is much more usual. Nevertheless it must be explained that, in the field of current cognitive sciences (psychology, artificial intelligence, cognitive neuroscience, cognitive education and cognitive anthropology), the term “cognition” is preferred instead of the traditional term “knowledge,” in order to highlight a double novelty in the conception of knowledge, which is peculiar to cognitive sciences, namely, that knowledge is information processing and that it is not a human privilege, but something shared with other animals and with some machines. And then the question arises: To what extent is it shared with animals and machines? We will examine firstly the part regarding animals.

It is possible to establish an initial notion of cognition very general and wide, according to which cognition would be every reception of information, in such a way that every living being would be a cognitive being. I think that this notion is clearly outrageous, but it has been defended, for example, by Humberto Maturana in “Biology of Cognition,” where he said: “Living systems are cognitive systems, and living as a process is a process of cognition. This statement is valid for all organisms, with and without a nervous system.”¹

A notion of cognition less general seems to me more reasonable, and then I esteem that we should distinguish two basic senses of cognition.² On the one hand, primary cognition, understood as a reception of information on the sensory and perceptual levels, and, on the other hand, proper cognition, understood as a process more active and complex of usage and manipulation of information. These two senses of cognition are related certainly with two kinds of representations.³ We can distinguish indeed two kinds of mental representations: primary representations and secondary representations. The former are the diverse sensations, such as colours, noises, smells, tastes, or feels, and also the different perceptions, such as a seen cat, a heard thunder, certain smelt perfume, a tasted sweet, or a felt pin prick.⁴ Moreover, secondary representations are more elaborate, including concepts, beliefs and inferences, and also memories

¹ MATURANA, H. R., “Biology of Cognition,” in MATURANA, H. R. and VARELA, F. J., *Autopoiesis and Cognition*, Reidel, Dordrecht, 1980, p. 13.

² Cf. MARTÍNEZ-FREIRE, P. F., “El impacto de las Ciencias Cognitivas en la Filosofía del conocimiento,” in MARTÍNEZ-FREIRE, P. F. (ed.), *Filosofía y Ciencias Cognitivas*, Supplement 3 of *Philosophica Malacitana*, Málaga, 1995, pp. 51-66.

³ Cf. MARTÍNEZ-FREIRE, P. F., “Epistemología con sujetos cognitivos,” in MARTÍNEZ-FREIRE, P. F. (ed.), *Filosofía actual de la Ciencia*, Supplement 3 of *Contrastes*, Málaga, 1998, pp. 95-118.

⁴ I have chosen the examples establishing a correspondence between visual, auditory, olfactory, flavour, and tactile sensations with visual, auditory, olfactory, flavour, and tactile perceptions.

and images, and equally feelings and volitions. The distinction between primary cognition and proper cognition is not sharp, because both of them are information bearing processes, and there are bordering cases (for example, a lot of perceptions entail the application of a concept more or less precise), but anyway I think that it is plain that a sensation of high heat and the belief that a cold shower will relieve this sensation do not belong to the same cognitive level. Summing up, primary cognition consists of a basically passive reception of information, whereas proper cognition is an active manipulation of information, which implies characterization, comparison, extraction, organization and invention of information, and also evaluation and arrangement to achieve aims.⁵

Hence, it seems that the animals with which we share proper cognition are, to begin with, our cousins, namely, bonobos and chimps, gorillas and orang-utans, and then, in a manner more or less clear and in diverse degrees, the rest of vertebrates (mammals, birds and reptiles, but also amphibians and fish).

Secondly, with which machines do we share cognition? First of all we should keep in mind that we are speaking about cognition as information processing, but also that we are talking about sensations or about beliefs and inferences as two levels of cognition, and therefore we must wonder whether it is meaningful to speak about information processing, sensations, beliefs and inferences in machines. The answer entails a lot of consequences, because an affirmative answer, I think, brought about the beginning of cognitive revolution and is the reason of the maintenance of cognitive sciences at present, whereas a negative answer brought about and results in the rejection of cognitive sciences as such.

Anyway, speaking about information processing, sensations, beliefs and inferences in machines is a case of analogical use. Only in analogical sense, in comparison with the corresponding animals and human processes, we can talk about these processes in machines. The analogy of computer, or better the analogy of programme, has been frequently used in cognitive sciences, meaning that human cognitive processes are, to some extent, comparable to the computer programmes. I esteem that it is perfectly genuine and even more clear to speak about *the analogy of human mind*, meaning that many mechanical cognitive processes are, to some extent, comparable with human cognitive processes.

However not only in the case that the analogy goes from machines to humans (and animals) but also in the case that the analogy goes from humans to machines, there must be something in common between machines and humans. This common aspect, such as we will see it with some detail in the next paragraph, lies in the fact that humans, animals and machines are information processing systems (IPS). From this point of view, sensations, beliefs and inferences in machines must be understood in analogical sense as well. And so we can answer our second question, saying that we share proper cognition (beliefs and inferences, memories and volitions, and maybe some degree of images and feelings) with computers and robots adequately programmed, that is, programmed following the analogy of human mind. Speaking in more precise terms, *Deep Fritz* programme, which is an excellent chess champion, or the robot *Spirit*, which is a clever geologist, share with humans' proper cognition.

⁵ The words chosen for the cases of proper cognition intend to be relevant: characterization for concepts, comparison for beliefs or judgments, extraction of information for inferences, organization for memories, invention for images, evaluation for feelings, and arrangement to achieve aims for volitions.

2. STRAIGHT AHEAD: NOTION OF COMPUTATION IN COGNITIVE SCIENCES

First of all the adequate place where to define the concept of computation is, obviously, the Theory of Computation itself. And therefore we should refer, although it will be briefly, to Alonzo Church (1903-1995) and to Alan Turing (1912-1954).⁶

Church, in his famous paper “An Unsolvable Problem of the Elementary Number Theory,” has defined the notion of an effectively calculable (that is, computable) function of positive integers identifying it with the notion of a recursive function of positive integers.⁷ This claim is known as Church’s Thesis, that can be formulated more simply saying that the functions which can be computed by a finite algorithm are precisely the recursive functions, or still more simply that all computable is recursive. In this way the intuitive and informal notion of computation is made coincident with the precise and formal notion of recursion.⁸ On the other hand, the recursive functions (*grosso modo speaking*) are the initial recursive functions (successor, sum, product, power, and arithmetic difference) plus the functions built out of the initial ones by means of certain operations (composition and minimization). As a parallel illustration, it is said that we have a recursive definition of something when the complex cases are defined using the simplest cases and these, in turn, are presented explicitly; for example, a natural number is defined recursively pointing out that 1 is a natural number, and that if n is a natural number, then $n+1$ is also a natural number. The general idea is that in a recursive process the complex cases are obtained out of the simplest cases.

Moreover, Alan Turing in his very important paper “On Computable Numbers” has defined a computable function as the function that can be computed (that is, calculated) by means of a machine described by him, and, for that reason, called “Turing machine.”⁹ This machine consists in a device (for examining, for writing, and for storing information) and in a potentially infinite tape, divided into squares each of them capable of bearing a symbol; the device scans a single square at a time, and can erase or write on it, and also can go a square to the right or go a square to the left in order to continue its examination; but it should be emphasized that the device has internal states which are the total sum of information stored in a given moment. This definition of computable function is called “Turing’s Thesis,” which can be formulated simply saying that the functions that can be computed by a finite algorithm are exactly the T-computable (Turing-computable) functions.

However, since it is proved that Church’s Thesis and Turing’s Thesis are equivalent, both statements can be united in the Church-Turing’s Thesis establishing that all that can be made by an algorithm can be made by a computer. Indeed the notion of effectively calculable (from Church’s Thesis) points out that we have an algorithm at our disposal, that is, a mechanical procedure consisting of explicit rules that produce an answer in a finite number of steps; and in

⁶ Cf. MARTÍNEZ-FREIRE, P. F., *La importancia del conocimiento. Filosofía y Ciencias Cognitivas*, 2nd ed., Netbiblo, A Coruña, 2007, pp. 117-127.

⁷ See CHURCH, A., “An Unsolvable Problem of the Elementary Number Theory,” *American Journal of Mathematics*, v. 58, n. 2, (1936), pp. 345-363. Reprinted in DAVIS, M. (ed.), *The Undecidable*, Raven Press, Hewlett, NY, 1965, pp. 89-107.

⁸ A classic place for the study of recursive functions is KLEENE, S. C., *Introduction to Metamathematics*, North-Holland, Amsterdam, 1952.

⁹ Cf. TURING, A., “On Computable Numbers, with an Application to the *Entscheidungsproblem*,” *Proceedings of the London Mathematical Society*, Series 2, v. 42, (1936-1937), pp. 230-265. Correction in *Proceedings of the London Mathematical Society*, v. 43, (1937), pp. 544-546. Reprinted in DAVIS, M., *The Undecidable*, pp. 116-154.

turn a Turing machine (from Turing's Thesis) is really the general and abstract description of a computer. In conclusion, from the point of view of the Theory of Computation, computation means a calculation process following an algorithm.

Nevertheless there is another concept of computation, which we can find repeatedly in cognitive psychology textbooks, and which was studied and worked out by Allen Newell (1927-1992) and Herbert Simon (1916-2001).¹⁰ It is the notion of information processing system (IPS). Indeed these cognitive scientists published in 1972 their book *Human Problem Solving*, where a detailed characterization of an IPS can be found.¹¹ In the epilogue of the book they put forward that, although they have directly studied human behaviour, programmed computer and human problem solver are both species belonging to the genus IPS.¹² Summing up, we can speak about an information processing system thesis (IPST), according to which every cognitive agent (human, animal, or machine) is an IPS.

Later, in their communication "Computer Science as Empirical Inquiry," Newell and Simon proposed the so called "hypothesis of physical symbol system" (HPSS), which is equivalent to IPST.¹³ This hypothesis defends that a physical symbol system has the necessary and sufficient means for general intelligent action. That is to say, any system that exhibits general intelligence will prove upon analysis to be a physical symbol system, and conversely any physical symbol system of sufficient size can be organized further to exhibit general intelligence. And general intelligent action indicates the same scope of intelligence as we see in human action, that is, a behavior appropriate to the ends of the system and adaptive to the demands of the environment.

But certainly we should specify what a physical symbol system (PSS) is. This task was accomplished by Allen Newell in his paper just entitled "Physical Symbol Systems."¹⁴ A PSS consists of a memory, a control, a set of operators, an input, and an output. In addition a PSS is a machine which exists in an environment consisting of objects, distributed in a space of locations. The inputs are information about the objects whereas the outputs are in turn information about the modification or creation of the objects. The external behavior of PSS consists of the outputs it produces as a function of its inputs, but the internal states of the system consist of the state of its memory and the state of the control. In conclusion, from the notion of an IPS, computation means the information processing made by a PSS.

However it is convenient to analyze in detail the concept of PSS, and its possible relation to the concept of Turing machine (TM). To begin with, although in the concept of TM the semantic aspects are not excluded, because the signs manipulated can be representational symbols, in the concept of PSS the semantic and also interpretation aspects are more explicit. Indeed the control of the system continuously interprets every expression, it interprets data and programmes as

¹⁰ For example, at the beginning of cognitive psychology in MILLER, G. A., GALANTER, E. and PRIBRAM, K., *Plans and the Structure of Behavior*, Holt, Rinehart and Winston, New York, 1960, and also in NEISSER, U., *Cognitive Psychology*, Meredith, New York, 1967, and even more clearly in LINDSAY, P. and NORMAN, D. *Human Information Processing: An Introduction to Psychology*, Academic Press, New York, 1972.

¹¹ Cf. NEWELL, A. and SIMON, H. A., *Human Problem Solving*, Prentice-Hall, Englewood Cliffs, NJ, 1972, pp. 20-21.

¹² Cf. NEWELL, A. and SIMON, H. A., *Human Problem Solving*, p. 870.

¹³ Cf. NEWELL, A. and SIMON, H. A., "Computer Science as Empirical Inquiry: Symbols and Search," *Communications of the Association for Computing Machinery*, v. 19, n. 3, (1976), pp. 113-126.

¹⁴ See NEWELL, A., "Physical Symbol Systems," *Cognitive Science*, v. 2, n. 4, (1980), pp. 135-184.

well, and within the latter it interprets symbols and their roles. On the other hand, among the described operators, the assign operator plays an important role, since it establishes a basic relationship between a symbol and the entity to which it is assigned. Even more important the concept of designation or representation is, for Allen Newell, the most fundamental concept for a symbol system.¹⁵ Besides, in his paper of 1980, Newell shows that an arbitrary Turing machine can be correctly simulated by a PSS.¹⁶

Moreover, the HPSS can and must be understood as the basic thesis of cognitive sciences, applicable equally to psychology and to artificial intelligence. That means that a PSS is an abstract description as much of a human or animal (at least vertebrate) agent as a computer or robot (properly programmed). In all these cases it is possible to speak about unit of inputs (receptors), unit of control with its operators, memory, and unit of outputs (motors), and also in all these cases it is possible to talk about information processing agents.

Nevertheless there is an aspect in the HPSS which we should consider with attention. In the very terms of the hypothesis, a close relation between a symbol system and the intelligence in human sense is established. I think that certainly on the occasion of the birth of artificial intelligence in 1956 — along the meetings that took place at Dartmouth College — the aim was to simulate the human intelligence, but also the central concerns of psychology in every time have been about intelligent activity. Both facts explain the major importance that the HPSS gives to intelligence, in such a way that now we can precise that proper cognition is fundamentally intelligence, and around it we find the processes that are its bases (such as concepts and beliefs), the processes that help and complete intelligence (such as memories and images) or the processes that qualify intelligence (such as feelings and volitions).¹⁷ On the other hand, intelligent processes should be understood as problem solving processes that use typically reasonings or inferences.¹⁸

In these conditions the claims put forward by Rodney Brooks about an artificial intelligence without representations,¹⁹ and about having eliminated cognition establishing a direct connexion between sensation and action are in general terms unacceptable.²⁰ Indeed Brooks defends that his autonomous mobile robots (“Allen,” “Herbert,”²¹ or “Genghis”) use their own world as their best model; according to Brooks when we examine intelligence at a very simple level, we find that the explicit representations and the models of the world simply disappear, and it turns out to be better to use the world as its own model, in such a manner that representation is the wrong unit of abstraction in order to build most of the intelligent systems. Brooks has built some interesting insect-like robots employing what he calls “subsumption architecture,” that is, several layers of subsystems of control added one after the other without any central system. His main ideas, he tells us, are situatedness, embodiment, intelligence (understood as determined by a dynamic of

¹⁵ Cf. NEWELL, A., “Physical Symbol Systems,” p. 156.

¹⁶ Cf. “Physical Symbol Systems,” pp. 151-154.

¹⁷ I can say that very often my reasonings depend on what I feel or I want.

¹⁸ Cf. MARTÍNEZ-FREIRE, P. F., *La importancia del conocimiento. Filosofía y Ciencias Cognitivas*, 2nd ed., pp. 205-213.

¹⁹ Cf. BROOKS, R., “Intelligence without Representation,” in HAUGELAND, J. (ed.), *Mind Design II*, The MIT Press, Cambridge, MA, 1997, pp. 395-420.

²⁰ Cf. BROOKS, R., *Flesh and Machines: How Robots will Change Us*, Pantheon, New York, 2002, p. 36.

²¹ The allusion to Allen Newell and to Herbert Simon is clear.

interaction with the world) and emergence, and all these ideas have led him to the new style of artificial intelligence named “behavior-based robotics.”

It seems clear that Rodney Brooks is aware of the exact value of his artificial intelligence, namely, that his robots are very effective in merely motor tasks, but they are not properly intelligent since they have not inferential capacities. And nevertheless, in the so called “embodied cognition” (which I intend to analyze in the next paragraphs) Brooks is reputed as one of the best examples.

As early as in 1991, cognitive scientist David Kirsh had criticized Brooks’ position in artificial intelligence, in his paper “Today the Earwig, Tomorrow Man.”²² For Kirsh, although sometimes we can change representation by control, a really intelligent behavior needs concepts, and with them representations, because without these a theory of perception is not possible, nor a theory of learning nor a good theory of control. Personally I think that we should not confuse cognition (in particular proper cognition) and motor ability. Brooks’ robots exhibit effectiveness without intelligence, and a mechanism can be very effective without being intelligent, for example our digestive system; Brooks himself, when describing the robots in our future life, in his book *Flesh and Machines*, calls them dumb and simple robots.²³

In conclusion, although the sympathizers of “embodied cognition” esteem Brooks’ artificial “intelligence” as a good example of embodied cognition, I think that it is plain that it is not a case of cognition nor of embodiment.²⁴ On the one hand Rodney Brooks’ robots are not properly intelligent, and so they are not examples of proper cognition. On the other hand they have not a biological body, which is the characteristic of (clearly understood) embodiment.

In addition to that, Larry Shapiro in “The Embodied Cognition Research Programme” defends that among the most famous success stories in embodied cognition are Brooks’ robots and Esther Thelen’s work on the development of motor behavior in infants.²⁵ Indeed Esther Thelen (1941-2004) and Linda B. Smith published in 1994 *A Dynamic Systems Approach to the Development of Cognition and Action* where they studied the problems about human development from the example of the ontogeny of erect locomotion.²⁶ For them, all normal human infants learn to walk upright not as a prescribed, logically inevitable process, but as a confluence of available states within particular contextual opportunities. Among these states are anatomical and neural elements that have a phylogenetic history, motivations to move more efficiently, a shared task environment including support surfaces, gravity and things to hold onto, and parenting that facilitates certain sensorimotor configurations. Summing up, human development does not follow a pre-established plan, nor even there are plans or representations. A dynamic account of early action and cognition can be extended to higher cognitive processes; a cognition that

²² Cf. KIRSH, D., “Today the Earwig, Tomorrow Man,” *Artificial Intelligence*, v. 47, n. 1-3, (1991), pp. 161-184.

²³ Cf. BROOKS, R., *Flesh and Machines*, p. 121.

²⁴ Cf. ANDERSON, M., “Embodied Cognition: A Field Guide,” *Artificial Intelligence*, v. 149, n. 1, (2003), pp. 91-130; and SHAPIRO, L., “The Embodied Cognition Research Programme,” *Philosophy Compass*, v. 2, n. 2, (2007), pp. 338-346; or CLARK, A., “Embodied, Situated, and Distributed Cognition;” in BECHTEL, W. and GRAHAM, G. (eds.), *A Companion to Cognitive Science*, Blackwell, Oxford, 1998, pp. 506-517.

²⁵ See SHAPIRO, L., “The Embodied Cognition Research Programme,” pp. 338-346.

²⁶ Cf. THELEN, E. and SMITH, L. B., *A Dynamic System Approach to the Development of Cognition and Action*, The MIT Press, Cambridge, MA, 1994.

is neither symbolic nor representational can be extended beyond the sensorimotor period to account for higher-order reasoning, language, logic, and metacognition.²⁷

About this point I think that two critical remarks should be made. Firstly, as in the case of Brooks, we have an example of motor ability, not of intelligence, and therefore we can not speak about proper cognition. Secondly, I esteem that it is not possible to account for proper cognition (which is beyond sensations and perceptions, including from concepts to inferences) without using representational devices.

3. FOLLOWING THE TRAIL: MIND AND ENVIRONMENT, ARTIFICIAL AND NATURAL MINDS

It turns out to be false to say, such as Larry Shapiro says in *The Mind Incarnate*, that the traditional view of the mind considers it as “envatted.”²⁸ That is to say, following the science fiction made up by Hilary Putnam in “Brain in a Vat,” human mind would be, according to the traditional conception in cognitive science, like the brain subjected to an operation by an evil scientist and placed in a vat, that is, removed from the body and separated from objects and persons around it.²⁹

As we have seen before, a PSS is a machine which exists in an environment consisting of objects, distributed in a space of locations.³⁰ Consequently mind, according to the traditional conception, is something situated in an environment.

If we move from mind in general and we focus on human mind, we can clearly notice in Ulric Neisser’s work a very reasonable conceptual evolution showing a cognitive conception of human mind.³¹

In the first textbook of cognitive psychology, entitled precisely *Cognitive Psychology*, Neisser defends that human mind is comparable to a computer programme, in so far as it processes information following certain rules, although human mental processes are far more complex than computer programmes.³² However in this book Neisser is not very interested in human physiology, and then it is possible to say that, to some extent, mind is disembodied. But in his book *Cognition and Reality* Neisser defends a more complete and embracing point of view about human mind.³³ Indeed Neisser had met James Jerome Gibson (1904-1979) at Cornell University, being influenced in some aspects by the inventor of ecological psychology, although without accepting his mistakes.

Gibson’s ecological psychology, as it is showed for example in *The Ecological Approach to Visual Perception*, stressed that human being and environment constitute an inseparable couple, where each of them implies the other, but Gibson offered a theory of vision, and in general a theory of perception, which can be considered as wrong, since he set forth that visual perception of environment is direct, not being mediated by retinean images, nor by neural images, nor by

²⁷ Cf. THELEN, E. and SMITH, L. B., *A Dynamic System Approach to the Development of Cognition and Action*, p. xxiii.

²⁸ Cf. SHAPIRO, L., *The Mind Incarnate*, The MIT Press, Cambridge, MA, 2004.

²⁹ Cf. PUTNAM, H., “Brains in a Vat,” in PUTNAM, H., *Reason, Truth and History*, Cambridge University Press, Cambridge, MA, 1981, pp. 1-21.

³⁰ Cf. NEWELL, A., “Physical Symbol Systems,” p. 142.

³¹ Cf. MARTÍNEZ-FREIRE, P., *La importancia del conocimiento. Filosofía y Ciencias Cognitivas*, 2nd ed., pp. 103-113.

³² See NEISSER, U., *Cognitive Psychology*, *passim*.

³³ Cf. NEISSER, U., *Cognition and Reality*, Freeman, San Francisco, 1976.

mental images.³⁴ Finally Neisser, in his new book published in 1976, proposes that the study of information processing should be made beyond the limits of laboratory, in such a way that cognitive psychologists should strive to understand cognition in the wild. In general Neisser embraces internal mental processes, and particularly cognitive schemas and maps, and real present environment as well.

Another basic aspect in cognitive sciences, besides the integration of mind and environment, is the integration of artificial minds and natural minds. This integration has, in my opinion, three senses, one theoretical, another methodical and a third sense practical. The theoretical sense is implied by the fact that an IPS or PSS is so much an artificial cognitive agent (computer or robot) as a natural cognitive agent (human or animal). On the other side, the methodical sense consists in the fact that we can employ concepts and strategies from psychology and neuroscience in artificial intelligence and, conversely, notions and instruments from artificial intelligence in psychology and neuroscience. There are many examples, but perhaps the best known example of use of neuroscience and psychology in AI is the field of artificial neural nets, and maybe the most outstanding example of application of the AI in neuroscience and psychology are the new techniques of exploration of the brain (such as positron emission tomography or magnetic resonance imaging). Finally, the practical sense is found in the fact of an ever growing integration of our human minds and artificial minds as a consequence of an increasing and intense use of intelligent computers and robots by humans, in so far as these computers and robots have become indispensable tools for us.³⁵ In conclusion, if we want to go on speaking about cognitive sciences we can not (nor we should) eschew neither psychology and neuroscience nor artificial intelligence.

4. EMBODIED COGNITION: PLEONASM OR OXYMORON?

To the best of my knowledge, all this issue about embodied cognition can not be understood without considering the repeated criticism by Hubert Dreyfus against artificial intelligence. Indeed Dreyfus is the most biting and persistent critic against AI, in the sense that he esteems that the claim of building intelligent computers is doomed to failure, because a computer can not really think neither simulate completely human intelligence.³⁶

The main text written by Dreyfus is his book *What Computers Can't Do*, which was published in 1972.³⁷ It has had a revised edition in 1979 (with a new introduction) as well as a new edition in 1992 with the new title: *What Computers Still Can't Do* (with another new introduction).³⁸ Hubert Dreyfus' criticism follows two different lines of argumentation. On the one hand he tries to show the falsity of the assumptions underlying, according to him, the AI. And on the

³⁴ See GIBSON, J. J., *The Ecological Approach to Visual Perception*, Houghton Mifflin, London, 1979. See also FODOR, J. A. and PYLYSHYN, Z., "How Direct Is Visual Perception?: Some Reflections on Gibson's 'Ecological Approach'", *Cognition*, v. 9, n. 2, (1981), pp. 139-196. Jerry Fodor and Zenon Pylyshyn insist on the fact that mind is a mechanism to manipulate representations, and that the direct perception (picking up the information about the environment which is contained in the ambient array) is something empty, because perception depends, in some aspects, upon inferences.

³⁵ Cf. MARTÍNEZ-FREIRE, P. F., "Filosofía de la robótica inteligente," in DIÉGUEZ, A. and ATENCIA, J. M. (eds.), *Genes y máquinas*, Publicaciones Universidad de Málaga, Málaga, 2006, pp. 327-347.

³⁶ Cf. MARTÍNEZ-FREIRE, P. F., *La importancia del conocimiento. Filosofía y Ciencias Cognitivas*, 2nd ed., pp. 145-176.

³⁷ DREYFUS, H., *What Computers Can't Do*, The MIT Press, Cambridge, MA, 1972.

³⁸ DREYFUS, H., *What Computers Still Can't Do*, The MIT Press, Cambridge, MA, 1992.

other hand he underlines the peculiar aspects of human beings which will be never simulated by computers.

Regarding our subject I am interested in the second line of argumentation. Indeed, for Dreyfus, the peculiar characteristics of human beings which can not be imitated by computers (although they seem to underlie all intelligent behaviour) are three: 1) the role of the body in the organization and unification of our experience of the objects, 2) the role of the situation in which we are to give us a background to arrange without (rigidly) regulating our behaviour, and 3) the role of human needs and purposes to organize the situation, in such a way that the objects can be recognized as relevant and accessible for us. Hubert Dreyfus makes use of philosophers like Ludwig Wittgenstein (1889-1951), Martin Heidegger (1889-1976) or Maurice Merleau-Ponty (1908-1951), particularly these two latter, in order to base his conception of human being as an entity embedded in a situation and determined by his body.

Really — and rightly — Merleau-Ponty in particular in his book *Phénoménologie de la perception*, analyses the characteristics of human body and his role in human knowledge.³⁹ His central thesis can be noticed in the following paragraph: “If, reflecting about the essence of subjectivity, I find it linked to the essence of body and to the essence of world, then it is that my existence as subjectivity does not constitute but one with my existence as body and with the existence of world, and that finally the subject which I am, taken concretely, is inseparable from this body and this world.”⁴⁰ Therefore, we find in Merleau-Ponty a theorization about human subject as an entity in the world and in his own body. Yet we can and we should add that neither the common sense nor sciences (biology, anthropology, physiology, or psychology) have denied that human being has a body and that each human being has an own body, that is to say, that humans are embodied entities.

Hubert Dreyfus’ criticism against AI, in the sense that it is not possible to build computers which truly think nor even simulate completely human intelligence, makes him insist on the importance of the body for human intelligence, in such a manner that (not having a body) computers are certainly very far from human intelligence.⁴¹ In the chapter “The Role of the Body in Intelligent Behavior,” in his book *What Computers Still Can’t Do*,⁴² the expression “embodied agent” appears referring to human agents, and since then this expression has become very successful.⁴³

Moreover Dreyfus, more recently, also has criticized the alleged benefits of the Internet, employing again Merleau-Ponty’s ideas and the importance of human embodied capacities. Certainly, in his book *On the Internet*, Dreyfus questions the efficiency of learning through the Net, and also shows his lack of sympathy regarding the virtual embodiment in *Second Life*

³⁹ Cf. MERLEAU-PONTY, M., *Phénoménologie de la perception*, Gallimard, Paris, 1945.

⁴⁰ MERLEAU-PONTY, M., *Phénoménologie de la perception*, p. 467 (my translation).

⁴¹ This argumentation should be taken in its own terms, namely, the intelligence of computers is different from human intelligence, but should not be taken saying that there is not intelligence in computers. It would be like claiming that aeroplanes do not fly because they do not fly as birds do.

⁴² Cf. DREYFUS, H., “The Role of the Body in Intelligent Behavior,” in DREYFUS, H., *What Computers Still Can’t Do*, The MIT Press, Cambridge, MA, 1992, pp. 235-256.

⁴³ Cf. DREYFUS, H., *What Computers Still Can’t Do*, p. 255.

platform by Linden Lab (San Francisco).⁴⁴ His reason is that our body, including our emotions and moods, play a crucial role in our being able to make sense of things.⁴⁵

Within this trend of embodied cognition, George Lakoff and Mark Johnson are worth to be mentioned as well. They both have published *Philosophy in the Flesh*, but some of their ideas about embodied mind can be traced back to his previous book *Metaphors We Live By*.⁴⁶ Indeed in this work Lakoff and Johnson put forward the stance that our ordinary conceptual system, according to which we think and we act, is basically of metaphorical nature, being the essence of metaphor to understand and to experience a kind of thing in terms of another, for example to understand a discussion as a war. Now if almost all of our concepts are understood metaphorically, that is, in terms of other concepts, there must be some basic concepts which we understand without metaphors, directly. Among these are the human spatial concepts, such as UP-DOWN, FRONT-BACK, IN-OUT or NEAR-FAR, which arise from our bodily experience. In conclusion, the understanding of the world and of ourselves arises because the nature of our bodies and of our physical and cultural environments imposes a structure on our experience.

In *Philosophy in the Flesh*, Lakoff and Johnson start by showing that the three major findings of cognitive science are that the mind is inherently embodied, that thought is mostly unconscious, and that abstract concepts are largely metaphorical. Following these theses they undertake a revision of basic philosophical ideas and a revision of history of philosophy as well. Yet, regarding our issue, I am more interested in their views about embodied reason. Indeed Lakoff and Johnson defend that our conceptual system is grounded in, neurally makes use of, and is crucially shaped by our perceptual and motor systems; moreover, major forms of rational inference are instances of sensorimotor inference. In conclusion we have an embodied mind, that is, the mind is not separate from or independent of the body.⁴⁷

In my opinion, speaking about embodied cognition is either a pleonasm or an oxymoron. As it is well-known, a pleonasm consists in a repetition of words with equivalent meanings, for example “go up upstairs” or “go down downstairs.” However when we speak about cognition, as it was detailed before, we can refer either to the knowledge of animals and humans or to the knowledge of machines. If we refer to animal cognition in general and human cognition in particular, then it is obvious, according to the common sense, and it is inescapable, according to the sciences, that animals and humans are bodily entities, and therefore adding “embodied” to “cognition” is a case of pleonasm. On the other hand, if we refer to mechanical cognition, its existence taken for granted, it is also obvious according to the common sense and sciences that computers and robots have not a biological body, and therefore adding “embodied” to “cognition” is a case of oxymoron.

In relation with embodied cognition we find the situated cognition, although they are not always clearly distinguished. We can say that embodied cognition insists on that cognitive agent is endowed with a body, whereas situated cognition stresses that cognitive agent is situated in a

⁴⁴ Cf. DREYFUS, H., *On the Internet*, 2nd ed., Routledge, New York, 2009.

⁴⁵ Cf. DREYFUS, H., *On the Internet*, p. 121.

⁴⁶ See LAKOFF, G. and JOHNSON, M., *Philosophy in the Flesh. The Embodied Mind and Its Challenge to Western Thought*, Basic Books, New York, 1999, and LAKOFF, G. and JOHNSON, M., *Metaphors We Live By*, University of Chicago, Chicago, 1980.

⁴⁷ Cf. LAKOFF, G. and JOHNSON, M., *Philosophy in the Flesh*, p. 555.

particular environment. Yet, as we have seen before, since Hubert Dreyfus the role of the body and the role of situation in knowledge have been united.

Perhaps the main exponent of situated cognition is the anthropologist Lucy Suchman. Indeed, in 1987 she published her book *Plans and situated actions*, where she defends that all human actions are actions taken in the context of concrete and particular circumstances, that is, they are situated actions.⁴⁸ In addition, according to Suchman, from this thesis should be derived a new way of understanding the communication between human beings and machines. Suchman's point of departure is the comparison between the way of navigating represented by the Trukese (inhabitants of Truk Islands, in West Pacific) and the way of navigating represented by Europeans. The European navigator exemplifies the prevailing cognitive science model of purposeful action, that is, he navigates following a plan, derived from certain universal principles of navigation and essentially independent of the exigencies of his particular situation. Nevertheless, Suchman tells us, the Trukese navigator, although he has an objective, he does not have a plan of navigation, but he responds to the presented diverse situations in an *ad hoc* activity. Lucy Suchman considers that all purposeful actions are inevitably situated actions, that is, actions taken in the context of particular, concrete circumstances. Therefore it is doubtful that representations of actions, such as plans, can account for actions. And on the other hand the design of intelligent machines proposed by Suchman should deal with the diverse situations and actions that arise in the human-computer interaction.

Alonso Vera and Herbert Simon, in their paper "Situating Action: A Symbolic Interpretation," replied globally to the defenders of situated cognition and to Suchman in particular.⁴⁹ Against the global thesis that planning and representation are irrelevant in everyday human activity, Vera and Simon reply that a number of existing symbolic systems perform well tasks embedded in complex environments, whereas the systems proposed by the defenders of situated cognition are really symbolic and representational. Regarding to Suchman, they point out, among other issues, that for persons which perform risky tasks is very dangerous to abandon their plans, and that plans are not specifications of fixed sequences of actions but are strategies that determine each successive action as a function of current information about the situation.

On other side, Patrick Hayes, Kenneth Ford and Neil Agnew published in 1994 "On Babies and Bathwater. A Cautionary Tale," which is a fierce rejoinder, told as a tale, to the theses of situated cognition.⁵⁰ Illustrated with drawings, the tale tells how the situated cognition, played by the nanny Sitnanny, under the influence of the radical social constructivism, gets rid of representation, represented by the baby Repbaby, throwing the baby out with the bathwater. This story expresses the belief of the authors that the representational hypothesis is a very good idea, and that the fact that agents are placed in an environmental and social situation must not eliminate the idea of mental representation, in the same way that when washing the baby we should not throw out the baby with the bathwater.

⁴⁸ Cf. SUCHMAN, L. A., *Plans and Situated Actions. The problem of Human-Machine Communication*, Cambridge University Press, New York, 1987.

⁴⁹ Cf. VERA, A. H. and SIMON, H. A., "Situating Action: A Symbolic Interpretation," *Cognitive Science*, v. 17, n. 1, (1993), pp. 7-48.

⁵⁰ Cf. HAYES, P. J., FORD, K. and AGNEW, N., "On Babies and Bathwater. A Cautionary Tale," *AI Magazine*, v. 15, n. 4, (1994), pp. 15-26.

More recently Suchman has published *Human-Machine Reconfigurations. Plans and Situated Actions*, as a second edition of her previous book, where she extends her analysis about the interactions between human beings and intelligent machines in order to account for recent developments in technology.⁵¹ In this work Suchman relies on concepts such as the concept of figuration (representations of the world), borrowed from American feminist Donna Haraway, or on the concept of agency, borrowed from French sociologist Bruno Latour, in order to propose the interactions between human and machine in relational terms, in such manner that humans and artifacts are mutually constituted.

In this line of studies about human-computer interactions, united to the use of continental European philosophers, we also find the book written by Paul Dourish *Where the Action Is. The Foundations of Embodied Interaction*, considered by Michael Anderson (in his “Embodied Cognition: A Field Guide”) as one of the three selected contributions (together with Brooks and Lakoff and Johnson) in the field of embodied cognition.⁵² Dourish thinks that much of current cognitive science is based on a strict Cartesian separation between mind and matter, cognition and action. But the use of Martin Heidegger and Ludwig Wittgenstein, among others, will permit us to found a human-machine embodied interaction. Dourish’s interest in action, according to himself, is twofold: the action of embodied agents center stage, and his approach provides a way to understand the contributions and opportunities emerging from dynamic new forms of technological practice.

I prefer the answers given by Vera and Simon and Hayes and his colleagues, although I think that the distinction I am using between primary cognition (basically sensations and perceptions) and proper cognition (from the level of concepts to the level of inferences) must be kept. The primary cognition is fundamentally situated whereas the proper cognition admits, and usually employs, an uncoupling procedure regarding situations.

5. IS EMBODIED COGNITION A GOOD CONCEPTUAL REVOLUTION?

My criticism against embodied cognition is not accompanied by the belief that scientific progress in general and progress in cognitive sciences do not exist. Truly I assume the point of view that we human beings can make every science progress, included certainly the field of cognitive sciences. The question however is whether the conceptual changes proposed by the defenders of embodied cognition constitute a conceptual revolution, and, in the affirmative case, if this is a good conceptual revolution, that is to say, if it is progressive to join this revolution.

In order to make such analysis I will use Paul Thagard’s ideas included in his book *Conceptual Revolutions*.⁵³ One of the merits in his book is the attention paid to the concepts as basic elements in sciences, in such a way that his considerations about possible conceptual revolutions start with the notion of conceptual structure, goes on with the study of conceptual changes, and ends up with the revolutionary conceptual changes. On the other hand the point of view adopted is at the same time psychological and computational, within the cognitive turn in philosophy of science

⁵¹ Cf. SUCHMAN, L. A., *Human-Machine Reconfigurations. Plans and Situated Actions*, 2nd ed., Cambridge University Press, New York, 2007.

⁵² See DOURISH, P., *Where the Action Is. The Foundations of Embodied Interaction*, The MIT Press, Cambridge, MA, 2001.

⁵³ Cf. THAGARD, P., *Conceptual Revolutions*, Princeton University Press, Princeton, NJ, 1992.

and following the theses presented in his book *Computational Philosophy of Science*, in such a way that Thagard not only considers the psychological theories about concepts but also he presents ECHO, a computational model of theory evaluation.⁵⁴

Thagard proposes to think about concepts as complex structures, giving special priority to the kind-relations and the part-relations which permit to generate hierarchies, and expressing factual information by means of rules. For example, the concept WHALE includes kind-relations (cetacean, mammal, sea-creature), subkind-relations (blue whale, white whale) and part-relations (fins, tail); and the concept also includes rules of inference, such as “if x is a whale, then x swims.” However an understanding of conceptual revolutions, Thagard adds, requires much more than a view of the nature of isolated concepts, we need to see how concepts can fit together into conceptual systems.

These systems use five classes of links: i) kind links, which indicate that one concept is a kind of another (for example, canary is a kind of bird); ii) instance links, which indicate that some particular object is an instance of a concept (for example, Tweety is a canary); iii) rule links, which express general relations among concepts (for example, canaries have the colour yellow); iv) property links, which indicate that an object has a property (for example, Tweety is yellow); and v) part links, which indicate that a whole has a given part (for example, a beak is a part of a bird).

Regarding the conceptual change, Paul Thagard defends that a full theory of conceptual change must account for the four following phenomena: 1) development by discovery, in which someone sets up a new conceptual system, 2) replacement by discovery, when the new conceptual system fully supplants the old one, 3) development by instruction, when someone other than the discoverer becomes familiar with the new conceptual system, and 4) replacement by instruction, when someone other than the discoverer adopts the new conceptual system and abandons the old one.

Finally, a scientific revolution occurs only when a scientific community as a whole adopts a new conceptual system. In addition, a conceptual change, according to Thagard, is revolutionary if it involves the replacement of a whole system of concepts and rules by a new system. And the transition to new conceptual and propositional systems occurs because of the greater explanatory coherence of the new propositions that use the new concepts.

Paul Thagard illustrates his theory of conceptual revolutions studying seven cases: Copernican revolution, Newtonian revolution, the chemical revolution by Lavoisier, Darwinian revolution, the theory of relativity of Einstein, quantum theory, and the geological theory of plate tectonics. However he specifies that whereas Copernicus, Newton, Lavoisier, Darwin and the theory of plate tectonics are cases of supplantation or total revolution, Einstein and quantum theory are cases of sublation, that is, rejection and preservation at the same time of different aspects of the old theory, and therefore the revolution is not total.

Applying these points of view to our case of embodied cognition, I think that it is very convenient to make clear that cognitive sciences constitute a field of interdisciplinary research, where we find psychology, artificial intelligence and neuroscience, together with logic, linguistics, anthropology and education. The “coherent unifying theory,” in Thagard’s terms, which would be supplanted to occur a conceptual revolution, is plainly the information processing system thesis (IPST) I considered before. Certainly we could accept some aspects of

⁵⁴ Cf. THAGARD, P., *Computational Philosophy of Science*, The MIT Press, Cambridge, MA, 1988.

embodied cognition, particularly its insistence on the situated characteristic of all cognition (so much for a machine as for an animal), and then we would have a case of, in Thagard's terms, "incorporation," that is to say, the traditional cognitive science would be absorbed completely by a situated cognitive science. In fact Paul Thagard seems to be inclined to this solution when he defends, in his book *Mind. Introduction to Cognitive Science*, completing the classic computational-representational model of mind, as prevailing approach in cognitive science, with biological and social considerations.⁵⁵

Nevertheless the defenders of embodied cognition do not seem to accept this incorporation, nor a sublation (keeping essentials aspects), but they seem to claim the supplantation or to achieve what Thagard calls "disregard," that is, the total ignorance of the classic conception of cognitive sciences.

My own thesis is that embodied cognition can not claim the supplantation of classic cognitive sciences because it has not the global scope which these sciences truly have by integrating animal cognition and mechanical cognition. In other words, embodied cognition can not include in a coherent way artificial intelligence, since neither computers nor robots have a body, and therefore embodied cognition ends up in cognitive science as solely science of animal behavior. In addition to that, given the indeterminate way of speaking about knowledge in body or through body, embodied cognition could produce the end or contempt of cognitive neuroscience.

"Embodied cognition," in my opinion, is a wide denomination which embraces very diverse theories making it impossible to establish a clear coherent unifying theory.⁵⁶ The only common elements are the insistence in the role of body and of situation in knowledge, endorsed by Merleau-Ponty and Heidegger, and the denial of the representational theory of mind. However, nobody in his right mind refuses neither the importance of body in animal knowledge nor the relevance of situation in animal and mechanical knowledge. And it does not seem possible to abandon the thesis that proper cognition is representation.

Summing up, as embodied cognition can not supplant classic cognition neither is willing to sublate this (because embodied cognition does not want to keep the basic thesis of information processing system), in Thagard's terms, embodied cognition is not a conceptual revolution, and therefore it is not a good conceptual revolution either.

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⁵⁵ See THAGARD, P., *Mind. Introduction to Cognitive Science*, 2nd ed., The MIT Press, Cambridge, MA, 2005.

⁵⁶ In addition to the theories considered in this paper, we could add the enactive approach claimed by Francisco Varela (1946-2001), which I have criticized in MARTÍNEZ-FREIRE, P. F., "El enfoque enactivo en las Ciencias Cognitivas," *Ludus Vitalis*, v. XIV, n. 26 (2006), pp. 129-140, or also the dynamical hypothesis put forward by Timothy van Gelder, which I have criticized in MARTÍNEZ-FREIRE, P. F., "Being Inside: Putting Representation, Body and World Together Again," in MARTÍNEZ-FREIRE, P. F. (ed.), *Cognición y Representación*, Supplement 10 of *Contrastes*, Málaga, 2005, pp. 39-50.

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III

From Cognitive Science to Medicine

- 5. Conceptual Changes in Biological Explanations of Behaviour
- 6. Research on Neurodegenerative Diseases: Epistemological and Methodological Problems

CONCEPTUAL CHANGES IN BIOLOGICAL EXPLANATIONS OF BEHAVIOUR¹

José María Martínez Selva

Psychobiology studies the bases or biological mechanisms of behaviour and mental processes. It is a varied field of study in which terminological confusion abounds — it goes under the name of physiological psychology or behavioural neuroscience — and it takes in subdisciplines, or what some authors call related sciences, like neuropsychology, psychophysiology or cognitive neuroscience. Psychobiology is an interdisciplinary science which sits between psychology and biological sciences, especially those which study the nervous system, called neurosciences, although to a lesser extent it includes features of those sciences which study other systems like the endocrine, the cardiovascular and the immunitary ones. Psychobiology provides biological explanations for behaviour which help to understand it better and to predict it.²

1. SCIENTIFIC EXPLANATION AND PSYCHOBIOLOGICAL EXPLANATION

Scientific theory is a conceptualization (set of concepts and the relations between them) which seeks to build intelligible representations of what is. To do so it describes, defines and explains with precision the events it studies, their properties and their reciprocal relations.³ Scientific explanation, therefore, consists of establishing relations between facts, or variables, in this case biological ones, especially those related to the nervous system and behavioural ones. These relations are either unknown or, if known, are better described, in more detail and, where possible, quantitatively. The authentic explanation which enables prediction is the causal one and, when talking about neuronal mechanisms or bases, or in the broader sense biological ones, of behaviour, it is the causal relation between neuronal events and behaviour.

Psychobiological research rests on several research principles, of which the first is *mechanicism-reductionism*. Behaviour is the result of the activity of the nervous system which allows it and makes it possible. Although behaviour is shaped by external events, i.e. by experience, or interactions with the physical and social environment, the latter act through the nervous system. Mental processes are considered as a special type of behaviour that is only accessible to the person who experiences them, but they also have their origin in and depend on the activity of the nervous system. The relation that is sought is that the physiological activity is a necessary condition for the behavioural or the mental to occur.

¹ Research funded by grant PSI2008-04394/PSIC of the Spanish Ministry of Science and Innovation and FEDER funds. The author thanks Mario Bunge, Wencesalo J. Gonzalez and Jorge Mariño for their comments on this paper.

² Cf. BUNGE, M. and ARDILA, R., *Philosophy of Psychology*, Springer, New York, 1987; MARTÍNEZ SELVA, J. M., *Psicofisiología*, Síntesis, Madrid, 1995; ROSENZWEIG, M. R., BREEDLOVE, S. M. and WATSON, N. V., *Psicobiología. Una introducción a la Neurociencia Conductual, Cognitiva y Clínica*, Ariel, Barcelona, 2005.

³ Cf. BUNGE, M., *Scientific Research*, 2 vols., Springer, New York, 1967; rev. ed., *Philosophy of Science*, Transaction, New Brunswick, 1998; and WAGENSBERG, J., “Lo falso en el conocimiento científico,” *Letras Libres*, n. 87, (2008), pp. 28-30.

While Psychobiology does not deny the need for neuronal activity for mental processes to occur, these can be understood as properties or emerging functions of neuronal activity (emergentist materialism) or, from more materialist positions, as neural activity (theory of neural identity). However, it is not known how physicochemical neuron processes can lead to mental processes, i.e. what rules are responsible for the transformation of the objective properties of the neurons into subjective properties.⁴

One consequence of mechanicism is *localizationism*: the mechanisms which control or regulate behaviour are in some place. The complexity of behaviour means that there is no single structure involved in it, rather that distributed (i.e. located in different places) brain systems are taking part, and these are made up of structures located in different regions and with reciprocal connections.

In the second place, and tying in with the biological explanation of behaviour, there is the *evolutionary* principle which affects the psychobiological explanation on two accounts. On the one hand, and besides the existence of a shared genetic heritage in many species, it implies that the central nervous system is an outcome of evolution and it is possible that many genetic, cellular biology and nervous system phenomena studied in other species are similar to those at work in the human being.⁵ Such findings may be used to explain how the nervous system works and how it generates behaviour and mental processes. Indeed, scientific experience shows that many cellular mechanisms are similar: general cellular functions, genetic transcription, nervous impulse transmission, “second cellular messengers” or photoreception.⁶ A complete and honest explanation of behaviour must not only be compatible with contemporary biology, but must also be proposed at the most elementary biological level possible, i.e. at gene and cell level, which is usually referred to as “molecular,” to account for the neuronal processes occurring in the structures or systems which are relevant for its appearance.

But human behaviour is also the result of evolutionary processes of adaptation to changing environmental conditions, something which has helped species to survive. Many patterns of behaviour observed in non human mammals are similar or linked to a greater or lesser extent with human behaviour, and there are behaviours with strongly innate elements, as occurs in sexual, maternal or aggressive, and even in cognitive processes in species which are phylogenetically close to humans.⁷ So findings regarding the biological bases of behaviour in animals could, in certain cases, be applied to human beings. There may even be a genetic explanation for some

⁴ Cf. PUELLES, L. V., “Sustrato neural del pensamiento,” in GONZALEZ, W. J. (ed.), *Aspectos metodológicos de la investigación científica*, Ediciones Universidad Autónoma de Madrid and Publicaciones Universidad de Murcia, Madrid-Murcia, 1990, pp. 293-304.

⁵ On genetic aspects shared by humans and other species, see MOUSE GENOMA SEQUENCING CONSORTIUM, “Initial Sequencing and Comparative Analysis of the Mouse Genome,” *Nature*, v. 420, (2002), pp. 520-562, and THE CHIMPANZEE SEQUENCING AND ANALYSIS CONSORTIUM, “Initial Sequence of the Chimpanzee Genome and Comparison with the Human Genome,” *Nature*, v. 437, (2005), pp. 69-87.

⁶ Cf. KANDEL, E. R., “Mecanismos celulares del aprendizaje y sustrato biológico de la individualidad,” in KANDEL, E. R., SCHWARTZ, J. H. and JESSELL, T. M. (eds.), *Principios de Neurociencia*, McGraw-Hill, Madrid, 2001, pp. 1247-1279; and KANDEL, E. R., *In Search of Memory: The Emergence of a New Science of Mind*, Norton and Norton, New York, 2007.

⁷ The so called evolutionary psychology tries to explain in detail and on a greater or lesser empirical basis how some human behaviours are also in other species and are of an evolutionary origin, and therefore genetic, as is defended, among others, by BUSS, D. M., *The Handbook of Evolutionary Psychology*, Wiley, Hoboken, NJ, 2005. Many researchers have studied cognitive processes like working memory in monkeys, e.g. GOLDMAN-RAKIC, P. S., “Working Memory and the Mind,” *Scientific American*, v. 267, (1992), pp. 111-117.

types of human behaviour, even those to do with emotional or social conduct.⁸ This tendency to behave in a manner similar to other species would depend on genetic mechanisms, so in the final analysis the explanation would also have to be provided at cell level or at that of the neuronal systems and processes taking part. However, the emphasis of evolutionary explanations of human behaviour relies more on the continuity of species rather than on the differences among them, and this continuity is considered formally more than empirically. These theories propose that the human being is guided by instinctive and uncontrollable forces, as if they were a kind of innate wisdom, mainly related to sex and dominance. These social and archetypical drives would develop outside of culture and education that in turn would be overwhelmed by these genetic drives. In this way this perspective is an underestimation of the ability to learn and adapt, and of the strength of the social environment to shape behaviour. Complex social behaviours, such as the moral sense, do not derive from animal biology. Human behaviour is a product of both biological and cultural evolution.⁹

The preferred scientific method to find the biological explanation for behaviour is the experimental method which studies the effect of one or more variables (independent variables), which are manipulated or modified according to the experimenter's criteria and on the basis of previous theories and data on one or more other dependent variables whose values are measured or recorded, while other non relevant or strange variables which may be having an effect on the relation and which are not of interest are controlled during the whole process. The experimental method is based as well on other principles, such as *replicability*, i.e. the experiment can be repeated in the same conditions and with the same techniques, and *determinism* by which the same causes always give the same effects. The hypotheses which serve as the starting point for the experiment and which are tested describe the relation between the variables that is expected to be found — derived or deduced from more general theoretical principles (theories or models) or from earlier findings (relations that have been confirmed). The explanation contained in the hypothesis follows the *parsimony* principle, it should be as simple as possible and it refers to more general scientific principles or rules. These hypotheses solve or clarify a problem or a specific sphere and are tested in the experiment. Performance of an experiment implies creating an artificial situation which seeks to be akin to reality and which allows findings to be generalized and extended to similar situations in the easiest way possible.

The essence of scientific explanation is prediction, insofar as it can be stated that under certain conditions a system will react to a specific stimulus in a way which is also specific.¹⁰ Nevertheless, a prediction is not necessarily an explanation. We can approximately predict a natural phenomenon, e.g. the blossom period of a vegetal species, without explaining it. Repetition of an experiment and testing a theory are examples of prediction: anticipating how a dependent variable will react under certain conditions or to a given magnitude of the independent variable. Various factors, such as the type of sample or the group of subjects selected, how similar the conditions of the experiment are to those of real life (laboratory or field) or whether the strange variables are well controlled or not, will all determine whether

⁸ Cf. BUSS, D. M., *The Handbook of Evolutionary Psychology*, *passim*.

⁹ Cf. BUNGE, M., *Matter and Mind: A Philosophical Inquiry*, Springer, Berlin, 2010; and KAGAN, J., *An Argument for Mind*, Yale University Press, New Haven, CT, 2006.

¹⁰ Cf. SIMON, H. A., "What is an 'Explanation' of Behavior?," *Psychological Science*, v. 3, (1992), pp. 150-161. Reprinted in THAGARD, P. (ed.), *Mind Readings. Introductory Selections on Cognitive Science*, The MIT Press, Cambridge, MA, 1998, pp. 1-28.

the generalization of the results, and hence the confirmed hypotheses is greater or lesser. Repetition of findings by other researchers in other laboratories gives greater validity and wider generalization to the results.

One thing to be highlighted when using the scientific method in Psychobiology is the use of specific research techniques which hail from psychology, biological and physical sciences (electrophysiology, radiology, chemical analysis, biotechnology, optics) alike, in manipulating and controlling and recording variables, which is firm proof of its interdisciplinary nature. The use of different techniques (lesion, stimulation, genetic modification, microdialysis) to tackle the same problem may provide a convergent validation, which is scientifically more solid, as to which neuronal mechanism or mechanisms control a behaviour. However, the incorporation of new research techniques provides, from time to time, not only new data, but also new perspectives, focuses and ways of tackling a particular problem, and these suppose *conceptual changes* in the way behaviour is explained through its bases or biological mechanisms.

Other methods are used in psychobiology (observation, clinical method, correlation), but the best prepared method for establishing causal relations, or at least ones which are consistent among the different events, is the experimental method, and especially so when using techniques and information from the experimental sciences mentioned above. The remaining methods are useful at the outset of scientific study in a new field, such as when pathological cases which have not been described appear or when experimentation is not possible due, for example, to its not being possible to isolate the variables because of their complexity, as may occur when studying personality traits, or when variables are difficult to manipulate, i.e. one cannot provoke brain injuries to humans. It is not a question of marginal or isolated methods since the clinical method, or the intensive study of a case continues to be widely used.¹¹

1.1. The Search for Psychobiological Explanations

Psychobiological research is carried out following the principles described and it is used in highly specific areas or spheres of knowledge which are determined by the problem under study, the type of behaviours which best covers or represents one or more aspects of the problem and the variable or set of relevant biological variables that can be related to the behaviour or behaviours studied. The complexity of behaviour and the diversity of techniques and biological perspectives make for many ways of tackling the same problem and for many levels of analysis, from the most general, or *molar*, to the most detailed, or *molecular* and, consequently, for the use of different techniques and different types of biological explanations. A same problem, like the nature of the consolidation of memory, can be studied from different perspectives which could be along the lines of several aspects:

- What chemical substances or hormones favour or impair memory consolidation? Does the *cortisol* hormone favour the memory storage of a learned motor task?
- Which brain structure or structures intervene in memory consolidation? Does lesion of the *basolateral nucleus of the amygdala* hinder a learning task with aversive stimulation?

¹¹ Some 40,000 single case studies are published each year in health sciences, mainly on infrequent brain injuries or illnesses, for which there are not many data or in which it is not possible to set up experimental groups and compare them to control groups. Cf. ROSELLI, D., “Phineas Gage, ‘Tan’ y la importancia de los casos clínicos,” *Revista de Neurología*, v. 40, (2005), pp. 122-124.

- Whether the different types of existing memories (*implicit, explicit, episodic, semantic*, for example) also have different brain mechanisms and processes for consolidation. Does lesion of the hippocampus affect *semantic* and *episodic* memory in the same way?
- Whether there are differences of a genetic type between people who have good memory consolidation and those who do not. Which gene or genes are responsible? How do they act in the subject's interaction with his surroundings, e.g. through diet?

The biological variable is in any case linked to the behaviour under study as it sustains it, allows it or causes it, or, more frequently, it is directly or indirectly associated to the activity in the brain systems which, in the final analysis, sustain, permit or provoke it.

Let us consider first the *sphere* or *domain* in which we are working. Behaviour and its bases or biological mechanisms are not in general studied. Specific aspects of behaviour are broached which belong to other more general ones: attention, memory, motivation, emotion or decision making. So specific events are studied which represent aspects or properties of each of these spheres, e.g. what changes in cerebral electric activity occur when observing emotional stimuli of different emotional "load" or affective value, and in which region of the brain they are produced.¹² A further step forward in the explanation would be to identify the region or regions activated by the brain systems which participate in or sustain emotional behaviour. Elsewhere, the relationships between different types of behaviour have been studied: e.g. those between emotion and decision making which are expressed in problems of the type "Does emotion affect decision making?" which can be translated into the hypothesis, "If a positive emotional state (cheerfulness) is induced in the subject, the subject will take riskier decisions." The biological variables being measured in this case are useful to test if the emotions that were intended to be provoked are in fact elicited, because there exists a verified relation between such biological variables and the brain mechanisms that are activated during decision making.

Another aspect mentioned above is the level of analysis at which the question is tackled: we can talk about a *molar* level, which is more general, e.g. the attentional level of hyperactive children in the classroom, or of a more *molecular* level, the better or worse performance of a *specific attentional task* by such children and its relation to the cerebral electrical activity compared to non hyperactive children, or which brain neurotransmission systems on which attention depends are not functioning properly in these children, or whether these systems function more or less efficiently due to genetic inheritance or perinatal factors. It should be understood that the differences of level are differences of grade, so some approaches are more molecular than others. Biological study of behaviour tends to study the most molecular behavioural and biological variables possible, such as trying to elucidate the genetic and molecular aspects of a given behaviour. In the last instance, the aim is to discover on which neuronal, biological processes a behaviour depends, so establishing a strong relationship of dependence between the biological and the psychological event.

This search for molecular aspects often leads one to incline towards the so-called "model systems" or "model behaviours:" simple, well known behaviours which can easily be related to their biological bases. These behaviours should be representative or should be similar to other

¹² An example could be CARRETIÉ, L., HINOJOSA, J. A., ALBERT, J., LÓPEZ-MARTÍN, S., DE LA GÁNDARA, B. S., IGOA, J. M. and SOTILLO, M., "Modulation of Ongoing Cognitive Processes by Emotionally Intense Words," *Psychophysiology*, v. 45 (2008), pp. 188-196.

more complex ones, such that the findings in the model system or behaviour can be generalized without difficulty to the latter. For example, the habituation of a reflex may be a simple memory model in animals, like the *sea hare*, which allows a more molecular approach and identifies the underlying neuronal mechanisms.¹³ In other spheres, the model system or behaviour may be the *reaction time* to respond to a stimulus, or the time taken to answer a question or to a *moral dilemma*, or the *mirror-drawing experiment* (a type of motor learning) or *dichotic listening* (simultaneous presentation of two messages in both ears) in order to study the selective aspects of attention, to give some examples. In these cases we are dealing with *molar* type approaches, which may be related to electrophysiological or metabolic changes in different regions of the brain, which do not give information about the underlying neuronal mechanisms, other than in a very general way. Animal research allows *molecular* studies, which are easier to perform, are less costly, more reproducible and suppose fewer ethical problems. The behaviours studied are sometimes very simple, but the techniques are highly reliable and the effect of the findings is more permanent than those of more complex behaviours.

Model systems are an easy way to establish relationships between behaviour (simple, and representative of other more complex ones) and its biological bases. In certain circumstances molar type approaches also enable strong causality or dependence relationships to be formulated. Thus a cerebral lesion may totally or partially alter a more or less specific behaviour, e.g. memory, or certain types of emotions, or social behaviour, which could serve to infer a necessary relationship between the integrity of a brain region and a behaviour.

1.2. Causal Approaches and Correlational Approaches

It has already been mentioned that psychobiology has a preference to follow the experimental method, taking into account the level of analysis, the sphere in which one is working, the type of behaviour or the subjects under study. Moreover, there are two focuses in its application, the causal focus and the correlational, which respectively, although not exclusively, belong to the psychobiological disciplines known as physiological psychology and psychophysiology.

The causal, or purely experimental, focus is based on the manipulating of an independent variable belonging to the nervous system, e.g. a lesion or drug administration. Some times it is very difficult to put into use in humans on account of its harmful character. It is only possible to study the cerebral bases of a behaviour in humans a posteriori, in the case of injuries of different origin which allow causal relationships to be established between neuronal activity and specific behaviours. In contrast, research with animals is free of such constraints. The pharmacological technique, based on administering substances or hormones which presumably affect the functioning of the synapses in cerebral systems, and which cause changes in behaviour can also be used in human beings under certain circumstances. On the other hand, there exist reversible lesion techniques which can be applied to humans, like the *Wada test* (anaesthesia of one hemisphere) or *transcranial magnetic stimulation* which inactivates a limited area of the cerebral cortex by the application of a powerful magnet.¹⁴

¹³ Habituation is understood as the progressive decrease in intensity of a response or reflex as a consequence of repeated stimulation. Cf. THOMPSON, R. F. and SPENCER, W. A., "Habituation: A Model Phenomenon for the Study of Neural Substrates of Behavior," *Psychological Review*, v. 73, (1966), pp. 16-43.

¹⁴ See JUNQUÉ, C. and BARROSO, J., *Neuropsicología*, Síntesis, Madrid, 1994; and ROSENZWEIG, M. R., BREEDLOVE, S. M. and WATSON, N. V., *Psicobiología*, *passim*, for a description of exploration techniques of the human nervous system and of the experimental and clinical studies of brain lesions.

Lesion techniques apart, the study of the biological bases of behaviour in humans have traditionally used innocuous, i.e. non invasive techniques, to explore the activity of the central nervous system. When studying the physiological changes which accompany the performance of psychological processes, we can talk about physiological *correlates* of behaviour. The main techniques used have been *electroencephalography* and derived procedures like *brain evoked potentials* and *polygraphy*, i.e. the study of mainly bioelectrical changes which depend on the peripheral nervous system and, in the last instance, on the central nervous system. We talk of central correlates when studying activity directly generated in the brain, e.g. the detection of metabolic changes or the presence of a neurotransmitter or a substance, or that obtained from the electroencephalography, the study of the cerebral evoked potentials or the *magnetoencephalography*.¹⁵ On the other hand, the peripheral correlates are those obtained by polygraphic, electrophysiological techniques designed to study mainly the *electromyographic* (muscular) activity and that of the autonomic nervous system, which are related to behaviours and mental activity like attention or emotion. Their interest stems from the relation with the brain structures and processes which supposedly regulate the psychological process under study.¹⁶ For example, an increase in the sympathetic branch of the autonomic nervous system, that manifests itself and can be measured by heart rate acceleration, palm sweat or pupillary dilation is related to the effort needed to solve an arithmetic task. The brain mechanisms that make the performance of this and other related tasks possible increase at the same time as the sympathetic activity.

2. THE MAIN CONCEPTUAL FRAMEWORKS OF THE BIOLOGICAL FOCUSES ON BEHAVIOUR

The biological explanation for behaviour rests on the information and techniques of biological sciences which provide a scientifically supported view or a coherent representation of how the brain works and how it gives rise to behaviour and mental processes. Maybe because the behaviours studied are very specific, the recent findings or the new theories are included in the conceptual framework with which they are compatible. This general approach, or conceptual framework, has changed over time as scientific findings have been incorporated or new techniques have been used for the study of psychological and biological questions, especially to explore the nervous system, and this evolution presents a series of more or less general conceptual changes which are discussed below. Some of the new techniques, especially some of those which deal with the exploration of the nervous system and its representation in images, the so called *functional neuroimaging* techniques, which are also described below, are changing the way the biological explanation of behaviour is broached and are bringing with them new ways of understanding the relationships between the brain and behaviour.

A first approach to brain functioning was of an electrophysiological nature. The use of electrophysiological techniques, like the electroencephalography, which were based on the study of the electrical properties of the nervous system and their relation to behaviour dominated psychobiological research from the 1930s to the 1970s, a period in which the overriding conception was what we can call “bioelectric brain.” The recording of intracellular electrical activity, the

¹⁵ See below for a more detailed description of these techniques, section *Functional Techniques for the Exploration of the Nervous System*.

¹⁶ Cf. CARRETIÉ, L., *Psicofisiología*, Pirámide, Madrid, 2001; and MARTÍNEZ SELVA, J. M., *Psicofisiología, passim*.

electroencephalography, intracranial electrical stimulation and other related techniques provide important data which helped to understand the biological bases of behaviour. An example of this can be seen in explanations like the following:

- Performance of tasks in a conscious state, e.g. reading and understanding a text or solving a problem, is accompanied by a particular cortical electrical activity which is shown in the electroencephalogram by fast frequency, low voltage waves of *beta* or rapid *alpha* type. This brain electrical activity is in contrast with what can be observed when a person is at rest and with closed eyes, characterised by a dominance of a slower, synchronic alpha rhythm, which is more pronounced at occipital regions.
- Studies of lesion and electrical stimulation indicate that low voltage rapid electroencephalographic activity, also called “desynchronized,” is due to the starting up or “increase in activity” of the structure called *brainstem reticular formation*.¹⁷
- Conclusion: it is the activity of this last structure, the reticular formation, which arouses the individual, or bestows a state of alertness, and through its effects on the cerebral cortex and other regions, which are detected by the electrical changes recorded, enables or allows the mental activity or behaviour under study to occur (attention, learning or problem solving, for example).

One of the aims of psychobiology is precisely that: the identification or localization of the structures whose activities cause or provoke specific behaviours or mental processes — in this case, the state of alertness or awareness which make other more complex processes possible. In principle, localization precedes more molecular studies, e.g. the biochemical type processes which take place in the cells in these regions, or in specific brain systems, i.e. in different inter-connected structures which contribute to a single process. Knowledge of the bioelectrical activity accompanying a behaviour provides more information about its bases or mechanisms, which brain structures allow or provoke it, given that more than one structure may participate at the same time in one behaviour, and that this or the structures can vary in their complexity:

- Without the presence or activity of these structures there is no such behaviour. The lesion techniques which eliminate it would allow it to be demonstrated.
- The bioelectrical changes reflect those of the activity of the structure in question, such that the electroencephalography would reveal a null or lesser activity when the behaviour under study is not present. Likewise, the performance of a behaviour or a mental process would be accompanied by greater, e.g. faster, electroencephalographic activity in the corresponding structure or system.

A more detailed study, at molecular level, reveals that the bioelectrical changes detected in a brain region are, at the same time, the result or manifestation or other more fundamental changes of a biochemical nature, which need to be unravelled. The electrical activity measured is the consequence of the different and changing concentrations of ions to both sides of the cellular membrane, due to the entry and exit of the ions. The entry, for example, of calcium ions (Ca^{2+}) in the cell set off a series of events inside it which may favour or hinder the connections

¹⁷ Cf. GREY-WALTER, W., *The Living Brain*, Gerald Duckworth and Co., London, 1953; and LURIA, A. R., *The Working Brain. An Introduction to Neuropsychology*, Penguin Books, Harmondsworth, 1973.

between the neurons, or *synapses*, and which is reflected in the electrical changes detected from individual cells or sets of cells.¹⁸

Since the 1970s there has been a speeding up in the discovery of substances (neurotransmitters) which constitute the basis of neurotransmission or the passing of the nervous impulse through the neurons to the vertebrates. The participation of other substances in neurotransmission (receptors, transporters, neuromodulators) gives us more information about how the chemical transmission of the nervous impulse is produced between the neurons (through their links or synapses) and how this transmission or interneuronal communication, or synaptic transmission may be favoured or hindered. Advances in biochemistry lead to a new conception or representation of brain activities, the so called “neurochemical brain.” Brain processes, behaviour and mental activity are in the last instance a consequence of the presence and action of the different substances described in the neuron and its connections. Knowledge of these neurochemical mechanisms and processes is essential to understand and explain the relations between brain and behaviour in a more detailed and more molecular way.

It was discovered later that the activating reticular system mentioned above can be subdivided into different systems which are projected from the brainstem towards the anterior regions of the brain.¹⁹ Various neurotransmitters can be identified in these subsystems and so it is that we can talk about different ascending activating systems like *cholinergic*, *noradrenergic*, *dopaminergic* and *serotonergic* depending on the corresponding neurotransmitter. Other structures are added to these systems (*Meynert basal nucleus*) and hypothalamic activating systems (*hypocretinergic* and *histaminergic*), which help to explain the origin, maintenance and alternation of the waking state and of the two main types of sleep (*rapid eye movement sleep* and *slow wave sleep*), and the fluctuations not only in the state of activation or alertness but also in the mood. These activating subsystems participate differently in behaviours and mental processes, some are more important for emotions, others for focused attention, others for arousal or in one of the phases mentioned into which sleep is divided. Other systems, such as the GABA-ergics, which use as neurotransmitter the gamma-aminobutyric-acid (GABA), inhibit the abovementioned activating systems and play an important role in inducing and maintaining sleep.

The development of psychopharmacology reinforces this neurochemical conception of the brain. The effects of a wide array of substances which modify behaviour is proof of the existence of a basic neurochemical mechanism located in the structures cited or in their connections whose alteration affects the states of alertness, sleep or affect. Hence *monoaminoxidase* inhibitors (MAO), an enzyme which destroys the brain norepinephrine, favour its action in the synapses in which it participates as a neurotransmitter and improve the mood state. *Antidepressant tricyclic* psychodrugs, *amphetamines* and *cocaine* prolong the action of *norepinephrine* and other neurotransmitters in their synapses (they impede any excess being recaptured by the presynaptic neuron), and provoke euphoria and changes in behaviour similar to those of the MAO. Similar effects on mood have been found for drugs which enhance or inhibit *dopaminergic* synapses, which act on the brain reward system. *Serotonine* plays an important role in sleep and in alertness, e.g. it inhibits transmission of pain, it modulates the unfolding of

¹⁸ Cf. LUCK, S. J., *An Introduction to the Event-Related Potential Technique*, The MIT Press, Cambridge, MA, 2005, ch. 1, pp. 1-50.

¹⁹ Cf. VANDERWOLF, C. H. and ROBINSON, T. E., “Reticulocortical Activity and Behavior: A Critique of the Arousal Theory and a New Synthesis,” *Behavioral and Brain Sciences*, v. 4, (1981), pp. 459-514.

aggressive behaviours and causes changes in emotional states. Pharmacological interruption of the synthesis of *serotonine* induces transitory periods of depression in persons with a family history of this disorder. Selective inhibitors of *serotonine* reuptake (like the well known *Prozac*) are a family of antidepressant drugs which improve the state of mind and social behaviour, they impede action by transporters or proteins which are responsible for synaptic reuptake of the monoamines *serotonine* and *norepinephrine*, they increase the levels of these substances in the synaptic union and their action on the postsynaptic membrane.²⁰

All this does not mean that electrophysiological techniques should not be used. Quite the contrary, they indicate higher or lower activity in more or less located brain regions. Furthermore, there exist electrical phenomena which “accompany” or which are produced at the same time as, tasks are being performed or significant stimuli are detected or recognized, e.g. the recordings obtained using brain evoked potentials techniques. Advances in analysis techniques of electroencephalographic activity allow for better locating of the “sources” or regions from which the signals originate.²¹ Many researchers continue to use stimulation and electrical recording of individual neurons in different animals and preparations. New techniques like magnetoencephalography, based on the study of neuronal electrical activity through the small magnetic fields that the neural activity provokes in the brain, also work in this direction. But the underlying mechanism continues to be the same: ionic changes at both sides of the neuron cellular membrane.

Is it necessary to go to a yet more molecular level of events to explain the biological bases of behaviour? It is if one seeks to fully determine what the bases are. It is, as said above, a pragmatic matter. But it is not if the researcher is content with general explanations, of a molar type, for behaviour, e.g.: “the presentation of a visual affective stimulus causes the appearance of a cerebral electrical potential in the parietooccipital region which reaches its highest amplitude at around 700 milliseconds” or “depressed people show a more pronounced asymmetry in electroencephalographic activity in the frontal regions.” But a complete psychobiological explanation must be complete at the molecular level or, if not, it must be as detailed as possible and should specify the regions, nuclei, or neurotransmission systems involved.

The latest advance, which came about thanks to genetics and molecular biology, has been that of the role of genetic inheritance in behaviour. The genetics of behaviour already had a long tradition in psychobiology. However, the steps forward in the last 30 or 40 years have given more detailed knowledge about the mechanisms which favour inhibition or activation of the genes relevant to behaviour. These discoveries have allowed us to study the interactions between inheritance and environment: the effect of the physical, biological and social environment on the expression of genes and the changes in behaviour during the life cycle. One aspect in which these advances are crucial for understanding the biological bases of behaviour is that genetic changes, such as expression and inhibition of genes, may be mediating processes which constitute the biological basis of memory. In other words, it could be explained how the interactions between the organism and its physical and social environment cause cellular changes of a biochemical type which on occasions bring with them the activation of specific

²⁰ Cf. TRIMBLE, M. R., *Biological Psychiatry*, 2nd ed., John Wiley and Sons, Chichester, 1996.

²¹ Cf. CARRETIÉ, L., *Psicofisiología, passim*.

genes. We are facing a case or example of how experience modifies the functioning of the nervous system and, consequently, behaviour.

The studies by Eric R. Kandel²² on the habituation of gill withdrawal reflex in the sea hare, and by other researchers on the synapses of the hippocampus and other regions of the central nervous system of mammals lead to the discovery of the missing link between behavioural events which are produced as a reaction or response in the environment (the reiterated stimulation of sensory receptors and the subsequent *habituation* or *sensitization* of the behavioural response), the location of neurons where the changes are produced which lead to the habituation or sensitization of the response under study persisting over time (or, in other words, the memory of the habituation), and the complex synaptic or intercellular mechanisms which provoke the activation of the genes or the protein synthesis process and, as a result, neural growth and an increase in the synaptic contact surface between two neurons, so improving the transmission of the nerve impulse between them.²³ This has led not only to locating the “place” in the memory of a simple learning (habituation, sensitization), but also to the molecular mechanisms which are its base. These studies make one think that the cellular mechanism of the memory is the reorganization of systems and circuits or neuronal networks located in the brain as a result of experience. Psychobiological research explains how external events are, in certain conditions, able to provoke changes in the efficiency of the connections between neurons, and how individual experience can strengthen or weaken the neuronal connections. These synaptic changes may be passing or permanent (memory). Permanent changes activate genes and the protein synthesis process, a good example of the interaction between inheritance and environment.²⁴

This is not the only approach to knowledge of the genetic bases of behaviour, be they hereditary or the result of the interactions with the environment. The task of the behaviour geneticist is twofold. On the one hand, it explains the molecular mechanisms which go from the gene to the behaviour and to the various events which can modify them and which explain that the expression of a gene can manifest itself in behavioural changes or in the tendency to behave in a certain way. And on the other, which genetic mechanisms can explain the differences in behaviour which are observed in the general population. In other words: from the gene to the behaviour and from the behaviour to the gene. The genetic brain is inseparable from the neurochemical brain, and neurophysiological techniques should, in the final instance, lead to the use of genetical-biochemical techniques. General explanations of the relationships between genes and behaviour are not sufficient, as are those proposed by evolutionary psychology, if it is not explained which neuronal mechanisms of biochemical type are involved. It is in this context of genetic neurochemical brain that the new *Functional Neuroimaging* techniques appear.

2.1. Functional Techniques for the Exploration of the Central Nervous System

In recent years there has been a huge advance in functional techniques aimed at studying the activity of the human nervous system. A brief description of the most commonly used is

²² Cf. KANDEL, E. R., “Mecanismos celulares del aprendizaje y sustrato biológico de la individualidad,” in KANDEL, E. R., SCHWARTZ, J. H. and JESSELL, T. M. (eds.), *Principios de Neurociencia*, pp. 1247-1279; and KANDEL, E. R., *In Search of Memory, passim*. In the last study the author provides an autobiographical account of his discoveries on the cellular bases of learning.

²³ In this respect, see MORGADO, I., “Psicobiología del aprendizaje y la memoria: fundamentos y avances recientes,” *Revista de Neurología*, v. 40, (2005), pp. 289-297.

²⁴ Cf. SÁNCHEZ ANDRÉS, J. V., “Memoria y conocimiento,” *Revista de Occidente*, n. 272, (2004), pp. 62-87.

offered in this section. They are very varied and the type of activity detected may be bioelectrical (*electroencephalography* and the technique derived from (*evoked potentials*), magnetic (*magnetoencephalography*) or metabolic (*positron emission tomography* and *functional magnetic resonance*). Other techniques, such as the near infrared stimulation (NIRS) may be added to the list. These techniques detect and record changes in the brain's activity produced by the manipulation of the behavioural variables, such as the presentation of stimuli or the performance of tasks.

While *electroencephalography* detects the cerebral electrical activity obtained at the surface of the scalp, the *evoked potentials* show changes in cerebral electrical activity triggered by specific stimuli observed when filtering and transforming the electroencephalographic activity. The great advantage of these techniques is their temporal resolution: their fast development, in a question of milliseconds, corresponds to the speed of brain processes and mental activity. They manifest themselves as sinusoid waves of less amplitude than those of the electroencephalogram, which require computerized methods, especially signal averaging procedures and spectral analysis, if they are to be obtained and measured. They show how the electrical activity of the central nervous system is affected by the effect of a physical stimulus or a psychological process.

Magnetoencephalography consists of the detection, measurement and representation of the very small brain magnetic fields produced by neuronal activity. The temporal resolution is comparable to that of the electroencephalography, and is of the order of milliseconds. Its spatial resolution, or the possibility of locating precisely a focus or source of magnetic activity in the cerebral cortex, is higher than that of electroencephalography but lower than that of other techniques like functional magnetic resonance.

As of the 1990s, an important development occurs in research techniques aimed at ascertaining the metabolic activity of different brain regions. These techniques, especially metabolic functional neuroimaging ones, (*positron emission tomography* and, especially *structural* and *functional magnetic resonance*), allow the brain regions where the greatest activity is being produced during the performance of the task to be located with greater precision, as well as identifying substances, like a specific neurotransmitter, which are acting in those regions. The advance as compared to electroencephalography is notable: greater precision in the localization of the activity and the detection of this activity both in the brain cortex and in the subcortical regions. The innovation brought about by these techniques is based on the measurement of the metabolic changes in the neurons: the consumption of oxygen or glucose is greater in groups of neurons which are more active at any one moment. These techniques do not strictly provide a causal explanation, but rather a correlational one, since they point to neuronal changes which are concomitant with psychological processes. Metabolic functional neuroimaging techniques *have* a triple advantage:

- A more precise localization of the brain structures.
- A more direct link with the underlying cellular activity.
- Knowledge of changes in brain activity in humans as they perform activities, allowing the brain functioning to be made out nearly in real time.

The visual representations produced by neuroimaging techniques make scientific work more intelligible: they are colour mosaics with a meaning, which can be understood easily, almost at sight.

In a broad sense the expression “Functional Neuroimaging” is used to describe any *visual representation* of the activity of the human nervous system. Thus the conversion or transformation of the electroencephalographic and *magnetoencephalographic* activity into images leads to visual representations (*electroencephalographic mapping* or *magnetoencephalographic neuroimaging* or *evoked potential neuroimaging*) which situate or locate the activity in the brain cortex. As has been said, in recent years there has been an important boost in neuroimaging techniques based on the study of the brain’s metabolic activity (*Functional Magnetic Resonance* and *Positron Emission Tomography*). These functional neuroimaging techniques are also central correlates since they study brain activity directly, but with a much greater spatial resolution than Electroencephalography, Magnetoencephalography and evoked potentials, and this allows for better localization of where an increase in activity in groups of neurons, nuclei or brain systems is occurring. Furthermore, they are innocuous in the case of functional magnetic resonance and of a low invasive character in that of positron emission tomography.

Metabolic functional neuroimaging techniques represent the neuronal activity associated or related to specific behaviours and mental processes, with reference to anatomically well defined regions of the brain and to neuronal processes which are well known at the molecular level (metabolism, neurotransmission, synaptic modulation, bioelectrical properties, membrane potentials). They thus allow very exact relations to be established between mental processes, brain activity and some specific cellular processes.²⁵

Positron emission tomography uses drugs which emit radioactivity and which have the property of joining up with organic molecules associated with neuronal activity. They allow maps to be drawn which show the distribution in the brain of the product used. It is not a completely innocuous technique since it uses radioactive substances, which the body will eliminate in a relatively brief period of time.

Functional magnetic resonance detects brain activity by oxygenation of the brain tissue, i.e., the changes in the level of oxygen in the blood. It represents the activity of a large number of neurons and is based on the fact that neuronal activity and hemodynamics are united.²⁶ The hemodynamic changes are slower than the neuronal ones and so their temporal resolution, while greater than that of positron emission tomography, is lower than that of electroencephalography. At the same time, it provides a very precise anatomical image, and so its spatial resolution is greater and allows functional and anatomical data to be combined directly.

Data obtained from these techniques support the localizationist principle that behaviour and mental processes depend on the activity of brain systems or distributed “neuronal networks of centres.” They also provide a wealth of new information on the neuronal bases of behaviour, and so constitute one of the most powerful tools for the study of the brain in the intact human subject, since it is possible to locate better the brain mechanisms which are responsible for behaviour and mental processes.

They also complement other techniques well. They allow us, for example, to locate and quantify very precisely the extent of brain injuries in human beings and to measure the volume of tissue affected. Before, localization with sufficient detail was only available through autopsy.

²⁵ Cf. POZO, M. A., “Neuroimagen funcional: Una ventana abierta al funcionamiento del cerebro,” *Revista de Occidente*, n. 272, (2004), pp. 7-23.

²⁶ LOGOTHETIS, N., “What We Can Do and What We Cannot Do with fMRI,” *Nature*, v. 453, (2008), pp. 869-878.

In some cases functional neuroimaging techniques have provided convergent validation data of lesion studies. One example is the study of brain mechanisms in decision making in humans. The studies by Antonio Damasio and collaborators have shown that a portion of the *prefrontal cortex*, specifically the *ventromedial* sector, plays a fundamental role in human decision making.²⁷ This is demonstrated by the fact that people with lesions in this region do not perform well in a standard decision making task — the “Iowa Gambling Task.” At the same time, neuroimaging studies in healthy people reveal that performance of this task is accompanied by increased activity in the *ventromedial prefrontal cortex*.²⁸ Both lesion and functional neuroimaging corroborate the role of the ventromedial prefrontal cortex in decision making.

2.2. From Cognitive Psychology to Cognitive Neuroscience

One of the most interesting examples of the effects of the use of techniques to explore the central nervous system and its repercussions in the way of understanding behaviour comes from the use of non aggressive techniques to study the intact human brain so as to verify the findings of Cognitive Psychology, in the search for a biological bases for cognitive functioning or human information processing models. Initially, the use of electroencephalographic techniques, and especially those of evoked potential, allowed the evolution from a “brainless” cognitive psychology to the modern “cognitive neuroscience” as a science which integrates the mental with the biological.

Since its beginnings in the 1950s and 60s cognitive psychology has been concerned with the study and description of mental processes which take part in the detection and analysis of information, its storage, its retrieval and its use. For years it did not pay attention to the biological bases of behaviour, understanding that it was possible to explain psychological events independently of any physiological explanation, while claiming at the same time that the explanation at different levels did not deny the reduction of mental processes to neuronal ones.²⁹

The development of cerebral evoked potentials techniques reconciled cognitive psychology with the study of the central nervous system and its supporters recovered their interest in the biological mechanisms of behaviour. Some components (parts of the sinusoid wave) of the evoked potentials vary in their physical characteristics (amplitude, polarity and temporal pattern) according to the task being performed by the individual and the cognitive processes in play for the task to be accomplished. These variations in the parameters of the wave which constitutes the evoked potential reveal something about the brain mechanisms which sustain and participate in the process, although the “source” of these variations in the potential being measured cannot be located with much anatomical precision since the spatial resolution of this technique is low.

²⁷ Cf. DAMASIO, A. R., *Descartes' Error: Emotion, Reason, and the Human Brain*, Avon Books, New York, 1994. For an updated review see MARTÍNEZ SELVA, J. M. and SÁNCHEZ NAVARRO, J. P., “Decision Making and the Emotional Brain,” in LYNCH, T. E. (ed.) *Psychology of Decision Making in Medicine and Health Care*, Nova Science Publishers, New York, 2007, pp. 103-141; and MARTÍNEZ SELVA, J. M., SÁNCHEZ NAVARRO, J. P. and BECHARA, A., “Un sistema cerebral distribuido para la toma de decisiones,” *Sociedad Iberoamericana de Información Científica*, <http://www.siicsalud.com>. Published on line on March 16, 2009.

²⁸ Cf. NORTHOFF, G., GRIMM, S., BOEKER, H., SCHMIDT, C., BERMPHOHL, F., HELL, D. and BOESIGER, P., “Affective Judgement and Beneficial Decision Making: Ventromedial Prefrontal Activity Correlates with Performance in the Iowa Gambling Task,” *Human Brain Mapping*, v. 27, (2006), pp. 572-587.

²⁹ Cf. SIMON, H. A. “What is an ‘Explanation’ of Behavior?,” pp. 150-161. Reprinted in THAGARD, P. (ed.), *Mind Readings. Introductory Selections on Cognitive Science*, pp. 1-28.

In spite of this limitation, the technique has been revealed over the years as being a way of validating the theories and models of cognitive psychology.

The main advantage of evoked potentials is their speed, since they occur at the same speed, measured in milliseconds, as the mental processes presumably involved in the processing and analysis of information proposed by cognitive psychologists. Both the mental process and the electrophysiological changes can be easily related. A parallelism can also be established between the models of *sequential* analysis of information formulated by cognitive psychology and the brain activity which manifests itself in the evoked potentials. Moreover, there exists a certain conceptual likeness between the sequential analysis of information models, the data coming from chronometric techniques (like the *reaction time*) and the evoked potentials ones.

It can be said that this was the origin of the so called cognitive neuroscience. Functional neuroimaging techniques have continued to support this interpretation and are being used more and more. The advantages of cerebral localization which these techniques, especially functional magnetic resonance, offer have served to strengthen cognitive neuroscience and present it as a discipline which combines the physical and the mental.³⁰ New interpretations have been put forward for the relations between the neuronal and the biological which, as will be seen later, do not enjoy the support of all psychobiologists and neuroscientists.

3. FROM ECONOMIC DECISION MAKING TO NEUROECONOMICS

Decision making processes have been widely studied in both economics and in psychology and for many years the research was guided by the so called *utility principle* on which the *rational* or *normative* theory of decision making is based. The theory considers that humans are rational beings and, therefore, carry out weighted estimations which lead to rational decisions. Decisions would be guided by the estimation or reasoned calculation of the *utility* or expected benefit, so people would value the information available in each case and would maximize the expected benefits, so choosing those options of greatest *expected utility*.³¹ Consequently, choices are based on rational assessment of consequences and therefore depend on the balance between possible losses and winnings which can be anticipated in different situations, so the cost of the decision should be equal to or lower than the value expected as an outcome of the decision.

Utility is a very difficult concept to define and it has many subjective components, so the calculation that leads to many economic decisions is rational, but the truth is that decisions or bets with expected negative values persist, e.g. buying lottery tickets or taking out an insurance policy.³² Many decisions are taken on impulse, on the basis of previous experiences, on what you see or think others will do. The result has been a progressive “psychologization” of this concept. Amos Tversky and Daniel Kahneman put forward the *prospect theory*, which underlines the psychological and subjective aspects of decision making.³³ The value of a *prospect* is equal to

³⁰ Cf. KANDEL, E. R., “De las células nerviosas a la cognición: La representación celular interna necesaria para la percepción y la acción,” pp. 381-403.

³¹ See VON NEUMANN, J. and MORGENTERN, O., *Theory of Games and Economic Behavior*, Princeton University Press, Princeton, NJ, 1947.

³² Cf. MELLERS, B. A., “Choice and the Relative Pleasure of Consequences,” *Psychological Bulletin*, v. 126, (2000), pp. 910-924.

³³ Cf. TVERSKY, A. and KAHNEMAN, D., “Judgement under Uncertainty,” *Science*, v. 185, (1974), pp. 1124-1131; and TVERSKY, A. and KAHNEMAN, D., “The Framing of Decisions and the Psychology of Choice,” *Science*, v. 211, (1981), pp. 453-458.

the sum of the benefit of the results that can be experienced, taking into account the likelihood of their occurring. Unlike rational theory, not only is the expected result maximized, but the *confidence* that this will occur is also taken into account. In other words, the important thing is not the real probability but the expectation that some events, as a result or consequence of the decision taken, will occur. People do not always tend to choose the rational solution to a problem but the one which is most comfortable or the one the person likes most, and which solves the problem of taking a decision. People often act according to their mood. Moreover, decisions may be influenced by affective aspects of both the situation and the consequences of the decision. When there are divergences between the rational, cognitive evaluation of the risk of a decision and the emotional reaction to a decision situation, it is the emotional reaction which predominates. In these cases, emotions provide basic, imprecise or barely processed information on the behaviour options and lead to speedier decision making. A distinction is made between *anticipated* emotions, which come from the possible consequences the subject anticipates of his decision, and the emotions *experienced* while taking the decision. The incorporation of emotions into the study of decision making has set off a huge number of experimental research studies.³⁴

The introduction of functional neuroimaging techniques has enabled many researchers to explore which regions of the brain “intervene” or are activated during economic decision making. Simple decision making tasks are used to correlate brain activity with choice behaviours. These can be betting games or cooperative games of single, repeated or iterative trials, and changes in the brain activity of the participants are examined while they are performing them.³⁵

Neuroimaging techniques offer many contributions of a theoretical and experimental nature. In principle they have improved our understanding of psychological processes, e.g. the greater or lesser participation of emotions, including the balance between altruistic and selfish behaviours which comes into play when taking simple and complex decisions.³⁶ They also add to the knowledge of these processes since they show, almost in real time, the cerebral changes which presumably sustain them. In recent years there has been a deluge of research on the study of the neural mechanisms in economic decisions, a new field of science known as *Neuroeconomics*, backed up by the development and use of techniques of metabolic exploration of the brain activity.³⁷ It is an interdisciplinary field, as is decision making itself, from which it proceeds, in which psychological and economic efforts are joined by those of neuroscientists, and it is frequent for specialists from different areas to research together. *Neuroeconomics* describes “networks” or neuronal systems which are activated when making economic decisions which can help to “explain” the decisions made by economic actors and the relative weights of the different variables in such decisions. The development of this discipline has completely changed the scientific approach to this question and has gone beyond the borders of the academic world, and can be found in many economic publications of a general character.³⁸

3.1. New Biological Explanations of Behaviour

The result of the massive use of these techniques in all spheres of behaviour has brought with it some conceptual changes, which consist of forming hypotheses which apparently “explain”

³⁴ Cf. MARTÍNEZ SELVA, J. M. and SÁNCHEZ NAVARRO, J. P. “Decision Making and the Emotional Brain,” pp. 103-141.

³⁵ Cf. CAMERER, C. F., “Strategizing in the Brain,” *Science*, v. 300, (2003), pp. 1673-1675.

³⁶ Cf. “Decision Making and the Emotional Brain,” pp. 103-141.

³⁷ Cf. CAMERER, C. F., “Strategizing in the Brain,” pp. 1673-1675.

³⁸ For example, “Do Economists Need Brains,” *The Economist*, July 26, 2008, pp. 70-71.

or rather describe what the brain is doing and its various regions and, therefore, which systems regulate or govern a behaviour. This gives the impression that we “know” what is going on inside the brain and that certain mechanisms responsible for certain behaviours have been identified. In theory, these techniques locate and show the “network” or brain system activated when a subject performs a task. This network of structures identifies with the neuronal origin of the behaviour.

One example of this type of study is that performed by researchers who study the neuronal bases of “moral behaviour.” The observation of areas of the brain which are activated when people have to perform moral decision making tasks has led some neuroscientists to talk in terms of “a common neuronal substrate of moral decision making processes,”³⁹ which consists of a series of brain structures (*ventromedial prefrontal cortex, orbitofrontal cortex, posterior cingulate cortex and posterior superior temporal sulcus*) which generate the processes and subprocesses that lead an individual to choose a behaviour which he considers morally correct or appropriate in one of these dilemmas or to classify a response to them as appropriate or inappropriate. Neuronal “networks” or “matrices” can thus be established which, apparently, possess an explanatory value but which only highlight the comparative advantage of functional magnetic resonance over other techniques, which consists of a better spatial resolution, which leads to a better location of structures but not to a better understanding of the nature of the underlying mechanisms of these aspects of moral conduct.

An underlying assumption of these interpretations, and one which is directly related to localizationism is that of “modularity,” according to which the mind and the brain are divided into different parts or “modules” whose activity can be studied through functional magnetic resonance. These modules consist of neuronal circuits between which some functional segregation can be established: the modules are spatially separated and specialize in different functions.⁴⁰ However, many brain functions are performed in a distributed manner, so many regions are working at the same time in different functions, rather than one part working for one function. On the other hand, the modules may not be evenly represented or located in different brains, since anatomical differences exist between people. It is hardly surprising that some researchers who do not agree with the new interpretations and explanations have pointed out that the strong point of these techniques, the better location of the activity, may lead to a new phrenology which locates more or less active structures, but which does not explain what is really going on inside the brain.⁴¹

3.2. Problems and Limitations of Neuroimaging Techniques and of the Psychobiological Explanations they Offer

These techniques do not indicate “causes” nor do they provide molecular approximations, but they point towards the regions of the brain that may be controlling behaviours and, thus,

³⁹ HEEKEREN, H. R., WARTENBURGER, I., SCHMIDT, H., PREHN, K., SCHWINTOWSKI, H.-P. and VILLRINGER, A., “Influence of Bodily Harm on Neural Correlates of Semantic and Moral Decision Making,” *Neuroimage*, v. 24, (2005), p. 894.

⁴⁰ Cf. LOGOTHETIS, N., “What We Can Do and What We Cannot Do with fMRI,” pp. 869-878.

⁴¹ Cf. KRINGELBACH, M. and ROLLS, E. T., “The Functional Neuroanatomy of the Human Orbitofrontal Cortex: Evidence from Neuroimaging and Neuropsychology,” *Progress in Neurobiology*, v. 72, (2004), pp. 341-372, and even the declarations of the renowned researcher Robert D. Hare to the general publication *The New Yorker*, on the abuse of functional magnetic resonance data to explain behaviour in psychopaths: SEABROOK, J., “Suffering Souls. The Search for the Roots of Psychopathy,” *The New Yorker*, www.newyorker.com (access on 10 November 2008).

advancing our knowledge towards the location of the structures which govern or control them. The focus of the experiments is usually correlational, in which there is no manipulation of the central nervous system relevant to the task or to the dependent variable, in this case the realization of a behaviour. This correlational character limits the explanatory power in a “strong” sense, i.e. of a causal relation.

But greater metabolic activity in a structure (one of the main advantages of these techniques) may indicate both activation and inhibition. In other words, the structure that manifests itself as most active may, in fact, be exercising an inhibition on other regions. Distinguishing this is crucial from the functional viewpoint as it gives insights into the workings of the brain while a task is being performed. It is difficult to know beforehand if the metabolism manifested by a structure increases or decreases when it is inhibiting another. The circuits and the organization of the region of the brain under study need to be known, therefore, from other methods. What does it mean when one region is activated more than another when observing an affective visual stimulus or prior to taking a decision? Observation of greater activity in a region or structure says very little in principle about the real nature of the relations between the different structures or within the system which are activated when performing some behaviour.

Yet due to their very nature they can also show activation in other areas on account of other physiological processes which are unrelated to those needed to carry out the behaviour under study. The fact that a region is activated while a task is being carried out does not mean that that region is *necessary* for its execution. It may be activated because it is connected to the region that is necessary. There are also regions that may be always active regardless of the task, and which are involved in modulation functions like keeping the subject awake and active. If the activity in these unspecific regions is compared at rest and during performance of the task, the activity may not be detected since it is only that which differs between the two states.⁴²

The limits may reside also in the relevance of the activity of small populations of neurons as a differential response to different stimuli or situations, since their low intensity would not be detected or would pass unnoticed when using these techniques. The disperse representation of a function in very small areas made up of a small number of neurons may hinder knowledge of their functions. Often the magnitude of the magnetic resonance signal may not be able to reflect properly the differences between regions participating in the same function and between those which different tasks should provoke in the same region.⁴³

In short, these new techniques do not fully explain, but they do locate. They are an important tool for obtaining data, but they need to be complemented by other techniques like lesion ones or by the more molecular studies. As has been said, lesion techniques allow a causal approach. They confirm that a structure plays an essential role in the process or the behaviour being studied. In this line of complementing techniques, positron emission tomography, while possessing less temporal and spatial resolution than functional magnetic resonance (and hence less accuracy in

⁴² RORDEN, C. and KARNATH, H.-O., “Using Human Brain Lesions to Infer Function: A Relic from a Past Era in the fMRI Age?” *Nature Reviews Neuroscience*, v. 5, (2004), pp. 813-819.

⁴³ See LOGOTHETIS, N., “What We Can Do and What We Cannot Do with fMRI,” pp. 869-878; and RORDEN, C. and KARNATH, H.-O., “Using Human Brain Lesions to Infer Function,” pp. 813-819. These two studies review the limitations of functional brain imaging techniques and the conclusions drawn from using them. These works have elicited a bitter controversy on the validity of the conclusions of a good number of important research studies based on functional magnetic resonance on account of the lack of orthodoxy in the use of the statistical tests which support them, as is reflected in ABBOTT, A., “Brain Imaging Studies under Fire,” *Nature*, v. 457, (2009), p. 245.

localizing structures and their activity), may, in contrast, identify the neurotransmitters or other active substances present in various regions during the performance of a given task. Thus, to some extent, it is closer to the molecular mechanisms of behaviour.

As we indicated in an earlier study,⁴⁴ one valid scientific explanation would be one that described the role of the biological mechanisms (brain systems or structures, neurotransmitter neurons, drugs) in specific psychological processes (attentional tasks, specific emotions, decision making) as well as the quantitative or qualitative nature of such a relation (correlation, cause, interaction between variables), which means that an interdisciplinary approach is required. In the mean time, it should not be forgotten that techniques are not just techniques: they are linked to the particular way of solving a problem, implicitly or explicitly they include an approach to the problem and at times a change in the way it is broached. They require external validation by the other experimental sciences from which they proceed. Each problem requires a certain type of technique. The most appropriate will be that which provides information of the highest quality possible on the relations between the nervous system and behaviour, that which allows a more molecular approach, that which best adapts to the problem and to the specific behaviour under study and to the type of experimental situation, while not neglecting the possible existence of other more appropriate techniques. The best, however, will always be a combination of techniques.

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⁴⁴ Cf. MARTÍNEZ SELVA, J. M. and SÁNCHEZ NAVARRO, J. P., "Neuroeconomics and Decision Making: A Common Task for Psychologists, Economists and Neuroscientists," pp. 1-4.

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RESEARCH ON NEURODEGENERATIVE DISEASES: EPISTEMOLOGICAL AND METHODOLOGICAL PROBLEMS

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1. INTRODUCTION

Regarding the research on neurodegenerative diseases, and as a typical example of the different aspects involved in this research, one of the most relevant changes in the way to approach this scientific problem, is related to the discovery of the existence of stem cells in the adult nervous tissue. The scientific results and their recent chronological development are simply a logical consequence of one another. Spanish scientific contributions to this problem are relevant and are also included in this review.

Neurodegenerative diseases' features include in all cases that the functional impairment observed in patients correlates with cell death of specific neurons in specific brain nuclei or areas. Clinical symptoms differ depending on the neurons affected in each individual disease: memory loss and Alzheimer's disease, motor impairment and Parkinson's disease, cognitive impairment and senile dementia, etc ..., but in all cases they are all caused by neuronal death/degeneration. This attracted much attention among researchers and the number of publications devoted to the "cell death" issue notably increased. Parallel to this and somewhat later, the possibility of replacing these dead cells in different parts of the brain with cells capable of restoring the lost function began to be evaluated. Though these transplantation trials faced, from the very beginning, the well known graft-versus-host syndrome, it is worth mentioning the experimental auto-transplantation of dopaminergic neurons into the *substantia nigra* performed by a Spanish group.

Alternatively, there is interest in the use of embryonic stem cells in this field, but their proliferation control mechanisms are not well known, and therefore progress using these cells has slowed down and in some cases, has stopped.

The discovery of stem cells in the adult brain represented a change of direction in scientific proposals: if adult neurogenesis exists, the real solution would be to modulate their proliferation activity, with all the consequences derived from it and this will be discussed hereafter.

Considering the ethical implications of this issue, on the one hand, the use of stem cells, and on the other, the enormous social impact of these diseases, a mutual influence of the results of scientific publications and the public opinion (considering as a reference the mass media) has to be admitted in Spain. Part of the present paper will be devoted to analyze the influences and correlations of these two. Some classical authors distinguish between what things are and what they seem to be. Berkeley proposed *esse est percipi*, therefore what counts for different empiricist

perspectives is the perception (to be is “to be perceived”). This has caused many different problems in the past. If we consider that one thing is the research about neurodegenerative diseases with its epistemological and methodological contexts and another one is their public perception, it is (considered) important to take into account both spheres. Because in many instances social factors mean (cause) that some lines of research did not attract funding and also affect the public perception of these advances.

In 1969, the sociologist Robert K. Merton identified in the scientific community an accumulative dynamic of the allocation of funds, like prices, recognition, and the possibility of publishing in quality journals. He called it “St. Matthew effect,” from the passage of the Gospel that says: “For the one who has will be given more, and he will have more than enough. But the one who does not have, even what he has will be taken from him” (Matthew, 25, 29). Therefore, those who are in visible positions of prestige will have access to another resources and positions of visibility and so on. Merton considered this effect as dysfunctional to the individual scientists, that are penalized in the first stages of their activities, but functional for the joint system, because it facilitates selection from the enormous mass of unpublished works sent to the journals for publication.¹

We aim to analyze the research on neurodegenerative diseases on the basis of a conception of the advancement of science in which social factors might play a considerable role. Scientific knowledge advances, as Thagard mentions, by changes usually more conceptual than social, it has to be considered also that mass media can influence the advancement of science.² Research on Alzheimer’s, Parkinson’s or Huntington’s chorea has experienced several epistemological and methodological changes derived from the advances on stem cells research. Stem cells meant the introduction of a new paradigm, a fact that received great attention from the media.

From this initial perspective, we aim to analyze the possible correlation between the epistemological and methodological evolution of the research on neurodegenerative diseases and its growing presence the Spanish press associated with the growing presence of stem cell research, like general daily printed press, such as *El País* and *ABC*. For this purpose, we compare the data from scientific micromedia — represented in the databases Pubmed and ISI Web of Science — performing searches with appropriate keywords, with the ones obtained from the web databases of *ABC* and *El País*, from 1996 to 2006. We analyze their possible correlations to try to distinguish the stages that could be established in both fields, science and mass media, introducing also information about some milestones in the decade in both arenas: research and press, that may influence one another mutually.

2. THEORETICAL AND METHODOLOGICAL FRAMEWORK

As previously mentioned, the finding that the way the nervous tissue degenerates in those diseases (that will soon be called “neurodegenerative”) was different from the usual inflammatory process, and looked more like the “programmed cell death” process called apoptosis, raised (definitively) the public interest in both issues.

¹ Cf. BUCCHI, M., *Scientisti e antiscentisti. Perché scienza e società non sin capiscono*, Il Mulino, Bologna, 2010.

² Cf. THAGARD, P., *Conceptual Revolutions*, Princeton University Press, Princeton, NJ, 1992. See also THAGARD, P., *How Scientists Explain Disease*, Princeton University Press, Princeton, 1999.

John Kerr published in the early 70s the first data about apoptosis in tumors.³ This form of cell death typically affects scattered individual cells which condense and bud to produce many membrane-bounded fragments in which organelles appear intact when viewed by the electron microscope. These apoptotic bodies are then phagocytosed and digested by cells resident in the tissue. This process was first described in malignant tumors⁴ and afterwards it was shown that it could be stimulated by radiation and eventually regulated by hormones in healthy tissues.⁵ With time, a more general homeostatic function was attributed to apoptosis.

It was not until the 90s that the first scientific paper appeared demonstrating neuronal apoptosis as a mechanism of neuronal cell death and as a possible explanation for neurodegenerative diseases.⁶ The 90s was practically devoted to clarifying which mechanisms could trigger apoptosis in order to try to prevent its activation in neurons. Thus, the paradigm proposed establishes neuroprotection as the reduction, inhibition or delay of neuronal apoptosis. In other words, the valuable neuron, the number of which was (a) fixed (one) from early years of life, should always be preserved because its death was irreparable. This statement is still true in certain nervous tissue locations such as the retina, where the loss of photoreceptors leads to the irreversible loss of vision; thus, the study of cell death mechanisms in retinal degenerative diseases is still of great interest.⁷ One very practical example of these conceptual changes is how dentists have changed their treatments during the last two decades, in the past conservation and restoration of teeth was the main goal to achieve whereas today they tend to immediately remove damaged teeth in order to preserve maxillary bone and be able to achieve adequate implants: the new subspeciality of “implantology.”

The concept of tissue regeneration in the adult human that was taught in medical faculties in the late 70s and early 80s included exclusively bone marrow, gonads, liver and some epithelia. It was accepted that some birds,⁸ as well as some rodents, showed neurogenesis until they were adults, but this was explained as a slow maturation process rather than an effective tissue regenerating capacity, however this was not seen in humans.⁹

³ Cf. WYLLIE, A. H., KERR, J. F. and CURRIE, A. R., “Cell Death: the Significance of Apoptosis,” *International Review of Cytology*, v. 68, (1980), pp. 251-306; and KERR, J. F., “History of the Events Leading to the Formulation of the Apoptosis Concept,” *Toxicology*, v. 181-182, (2002), pp. 471-474.

⁴ See SEARLE, J., COLLINS, D. J., HARMON, B. and KERR, J. F., “The Spontaneous Occurrence of Apoptosis in Squamous Carcinomas of the Uterine Cervix,” *Journal of Pathology*, v. 5, (1973), pp. 163-169.

⁵ Cf. KERR, J. F. and SEARLE, J., “Deletion of Cells by Apoptosis during Castration-Induced Involution of the Rat Prostate. Virchows Arch B,” *Cell Pathology*, v. 13, (1973), pp. 87-102; WYLLIE, A. H., KERR, J. F. and CURRIE, A. R., “Cell Death in the Normal Neonatal Rat Adrenal Cortex,” *Journal of Pathology*, v. 111, (1973), pp. 255-261; and WYLLIE, A. H., KERR, J. F., MACASKILL, I. A. and CURRIE, A. R., “Adrenocortical Cell Deletion: the Role of ACTH,” *Journal of Pathology*, v. 111, (1973), pp. 85-94.

⁶ Cf. DIPASCUALE, B., MARINI, A. M. and YOULE, R. J., “Apoptosis and DNA Degradation Induced by 1-Methyl-4-Phenylpyridinium in Neurons,” *Biochemical Biophysical Research Communications*, v. 181, (1991), pp. 1442-1448.

⁷ See SANCHO-PELLUZ, J., ARANGO-GONZALEZ, B., KUSTERMANN, S., ROMERO, F. J., VAN VEEN, T., ZRENNER, E., EKSTRÖM, P. and PAQUET-DURAND, F., “Photoreceptor Cell Death Mechanisms in Inherited Retinal Degeneration,” *Molecular Neurobiology*, v. 38, (2008), pp. 253-269.

⁸ Cf. ALVAREZ-BUYLLA, A. and NOTTEBOHM, F., “Migration of Young Neurons in Adult Avian Brain,” *Nature*, v. 335, (1988), pp. 353-354.

⁹ Cf. MADEIRA, M. D., CADETE-LEITE, A., ANDRADE, J. P. and PAULA-BARBOSA, M. M., “Effects of Hypothyroidism upon the Granular Layer of the Dentate Gyrus in Male and Female Adult Rats: A Morphometric Study,” *Journal of Comparative Neurology*, v. 314, (1991), pp. 171-186.

Cerebral neurogenic capacity can reach ten thousand new neurons per day in the adult individual from brain resident stem cells, reported by the Spanish researcher Jose M. Garcia-Verdugo in cooperation with Arturo Alvarez-Buylla in 1999.¹⁰

In addition to this, another classical “dogma:” that adult stem cells could only regenerate the tissue where they were located or had been programmed was shown to be false soon after this discovery (that, by the way, applied very quickly to other tissues such as muscle, cardiac muscle or fat tissue) and it was. Biotechnological improvements allowed scientists to prove that bone marrow-derived adult stem cells could be used experimentally to repair damaged heart, muscle, brain, liver, etc. Likewise, brain and muscle stem cell-derived cell lines could contribute to lymph hematopoietic system regeneration. These evidences comprised a new concept, initially named transdifferentiation, that soon changed to the wider concept of stem cell plasticity, i.e. stem cells have the intrinsic capacity to execute a big variety of developmental genetic programmes where the decision on which one to activate is determined by the tissue environment (growth factors, cell-cell contacts, etc.).¹¹

The definite solution in this context that, of course, has not been reached would certainly be knowledge regarding which are the regulatory factors for the proliferation of these cells to be able to adjust precisely their proliferation in each individual case. Although it may sound unachievable, many advances in somatic cell therapy, including central nervous tissue, are occurring, though not at the velocity many desire.¹²

The perception of the advancement of science is situated between two extreme positions. On the one hand, scientifism considers science as “an impartial source of authority, and then, an appropriated base to find the right solutions for controversial public issues,”¹³ and, on the other, the limited connection with the public, as Fernandez del Moral notes, who maintains that science and technology have experienced a parallel development without having established a link between society and scientific advancement.¹⁴

The historical changes in the 60s influenced by postmodernism consolidated the idea that scientific activities are beyond historical modifications and have social implications. The deep question is if scientists, when they advance in their research, have to take into account or not epistemic values. There are three basic positions: some consider that they should only use epistemic values to decide and, as they incorporate non-epistemic values when they decide, they are irrational; others consider that they must use epistemic values when it is possible, but, for some important decisions, these are not enough, and then they should take into account non-epistemic considerations and use them. And, finally, there are some others that consider that

¹⁰ Cf. DOETSCH, F., CAILLÉ, I., LIM, D. A., GARCIA-VERDUGO, J. M. and ALVAREZ-BUYLLA, A., “Subventricular Zone Astrocytes Are Neural Stem Cells in the Adult Mammalian Brain,” *Cell*, v. 97, (1999), pp. 703-716; and DOETSCH, F., GARCIA-VERDUGO J. M. and ALVAREZ-BUYLLA, A., “Regeneration of a Germinal Layer in the Adult Mammalian Brain,” *Proceedings of the National Academy of Sciences of the United States of America*, v. 96, (1999), pp. 11619-11624.

¹¹ Cf. BERNARD, A., GONZALEZ, M. A. and MARTINEZ, A. C., “Células madre: promesas y realidades,” in RODES, J. (ed.), *Transplante de órganos y células. Dimensiones éticas regulatorias*, Fundación BBVA, Bilbao, 2006, pp. 243-253.

¹² An excellent analysis of what has been published in this realm: GARCIA OLMO, D., GARCIA-VERDUGO, J. M., ALEMANY, J. and GUTIERREZ-FUENTES, J. A. (eds.), *Cell Therapy*, McGraw Hill-Interamericana, Madrid, 2008. It includes a prologue by the Nobel Prize of Medicine and Physiology Dr. Edgard Donnall Thomas.

¹³ NELKIN, D., *Selling Science: How the Press Covers Science and Technology*, W. H. Freeman, New York, 1987. Translated into Spanish by Jorge A. Andrade Padilla: *La Ciencia en el escaparate*, Fundesco, Madrid, 1990, p. 76.

¹⁴ Cf. FERNANDEZ DEL MORAL, J., “Prefacio,” in NELKIN, D., *La Ciencia en el escaparate*, p. 9.

epistemic values are completely social and each one of them has some epistemic or cognitive content in itself.

The distinction epistemic/non-epistemic is not feasible for Kuhn.¹⁵ In his opinion, rationality cannot be reached by algorithms or any sophisticated process of statistic decision that has been used to define the rationality of the election and it has to be assumed to his universal use. Kuhn states that the human component is present in the labor of researchers, because science is a human activity and it consists in searching for knowledge to support decisions; a knowledge that is human.

This approach tends to an important methodological turn around: the scientific method cannot be a mere rational process based in an impersonal and ahistorical logic of research; there are several social, cultural and economical factors that influence the advancement of scientific research. Science is not always an isolated activity in the laboratories; it implies a complex science-technology system with a matrix of relationships between different subjects. This fact has its own influence in the communication process, so that scientific journalism does not only inform about researchers. The object of the news is not only the scientists, but also the administration, industry, the agents of science policy and the politicians in general; that is to say, “the object of information is the *Science and Technology system*.”¹⁶

Thomas Kuhn was the first person that contributed to break down the linear image of the scientific process of the methodological tradition received from the philosophers of verification/falsification e.g. Karl Popper. There is a variable of congenital knowledge that advanced moved by the changes in the historical environment. It depends on the consecutive election of paradigms and on social factors that are non-measurable with scientific methods.¹⁷

There are several authors who with Kuhn, from the 60s on made it possible an historical turnaround in the philosophy and methodology of science possible in such a way that scientific advancement has its own structural modifications, i.e., changes along time that fall into their reality beyond a temporal dimension. In this conception, historicity has a key role: “scientific method is not a matter of logic as it happens in neopositivism, and it is not either in consonance with the instant rationality that Popper defends. The new approach is based on the fact that science advances in a *procedural rationality* with historical features. Thus, there is no place for neopositivist’s linear and accumulative process, and it is not possible either that falsifications behave automatically as refutations.”¹⁸

Kuhn and Lakatos consider science as a social activity, because it is the result of a social endeavor along time, and it is not an impersonal or an abstract product. They consider the real references from theory, so theoretical framework, paradigm or research program, are employed

¹⁵ Cf. KUHN, TH. S., *The Structure of Scientific Revolutions*, International Encyclopedia of Unified Science: Foundations of the Unity of Science, v. 2, n. 2, The University of Chicago Press, Chicago, 1962 (2nd ed., 1970; and 3rd ed., 1996).

¹⁶ GRAIÑO, S., “Madurez del periodismo científico,” in Vv. AA. (eds.), *I Congreso Nacional de Periodismo Científico*, CSIC, Madrid, 1990, p. 157.

¹⁷ Cf. GONZALEZ, W. J., “Las revoluciones científicas y la evolución de Thomas S. Kuhn,” in GONZALEZ, W. J. (ed.), *Análisis de Thomas Kuhn: Las revoluciones científicas*, Trotta, Madrid, 2004, pp. 15-103; and GONZALEZ, W. J. (ed.), *Science, Technology and Society: A Philosophical Perspective*, Netbiblo, A Coruña, 2005.

¹⁸ GONZALEZ, W. J., “Las revoluciones científicas y la evolución de Thomas S. Kuhn,” in GONZALEZ, W. J. (ed.), *Análisis de Thomas Kuhn: Las revoluciones científicas*, pp. 33-34

as a focus to illuminate references.¹⁹ A result of this historical about-turn, which reaches its peak in *The Structure of Scientific Revolutions* by Thomas Kuhn, is that there are several important frames which support streams where social, cultural, political or economical external criteria are more important than internal ones such as language or structure of knowledge.

These are routes not foreseen by Kuhn. These roads go beyond the reach of history, philosophy and methodology of science, which were the fields that he studied in his career and went deep into the field of sociology of science, or move into the aspects of social anthropology. His papers are part of science, technology and society studies and they connect with the movements of public understanding of science. The key is then the social dimension of science that Kuhn accepts without reservation as a constituent factor of scientific activity: “Society today is suffused with technologies and with insights and beliefs derived from science. Increasingly in modern cultures, citizens think about themselves and their own lives through the lenses of science.”²⁰

Therefore, sociology of science is based on two aspects: sociology of the community of researchers, i.e., the one of the pure science and other ways of research, and the sociology of the relations of that community with the rest of the society.²¹ In this way, the growth of the social, political and economical importance of scientists — more relevant in the second half of the twentieth century — and the assumption of objectivity and impartiality disappeared, and this happens not also in the enterprises, but also among scientists. As science has grown as a profession, researchers want better grants, better equipment, etc.

They want politicians and legislators to consider them more seriously. And science cannot be separated from other cultural beliefs. “Scientific knowledge is based on observation but it cannot be exhaustively justified by observation alone. Apparently, therefore, science cannot be definitively separated from other cultural beliefs which also boast an observational basis.”²²

However, Thagard or Gonzalez consider that conceptual factors are more important than social ones in scientific revolutions: “Thus *Conceptual Revolution* shows an internal perspective of scientific revolutions: it presents an alternative to the Kuhnian attempt to harmonize two sides — internal and external — also when he finally gives more weight to the first.”²³

Thagard suggests that a conceptual change is revolutionary if it includes the replacement of one set of concepts and rules by another new set. Thagard’s conceptual revolutions are different from Kuhn’s Scientific Revolutions. He defends the explanatory coherence that criticizes all the difficulties of the rationality of Science and he (re)assures the comparability

¹⁹ Cf. LAKATOS, I., “Falsification and the Methodology of Scientific Research Programmes,” in LAKATOS, I. and MUSGRAVE, A. (eds.), *Criticism and the Growth of Knowledge*, Cambridge University Press, Cambridge, 1970, pp. 91-196; and LAKATOS, I., *The Methodology of Scientific Research Programmes, Philosophical Papers, vol. 1*, edited by J. Worrall and G. Currie, Cambridge University Press, Cambridge, 1978.

On his view, see GONZALEZ, W. J., “La Filosofía de I. Lakatos, 25 años después: Del ‘giro histórico’ a la incidencia metodológica en Economía,” in GONZALEZ, W. J. (ed.), *La Filosofía de Imre Lakatos: Evaluación de sus propuestas*, UNED, Madrid, 2001, pp. 13-103.

²⁰ YEARLEY, S., *Making Sense of Science. Understanding the Social Study of Science*, Sage, London, 2005, p. vii.

²¹ Cf. YEARLEY, S., *Making Sense of Science. Understanding the Social Study of Science*, p. vii.

²² *Making Sense of Science. Understanding the Social Study of Science*, p. 4

²³ “Así *Conceptual Revolutions* ofrece una perspectiva interna de las revoluciones científicas: presenta una alternativa al intento kuhniano de armonizar las dos facetas — la interna y la externa —, aun cuando finalmente se decante más por la primera,” GONZALEZ, W. J., “Las revoluciones científicas y la evolución de Thomas S. Kuhn,” p. 71.

of theories opposing Kuhn's incommensurability. Thagard accepts then objective elements in the interpretations of revolutions.

Thagard assures in his book *Conceptual Revolutions* that the aim of his work implies the omission of the discussion about the social context of scientific change and that conceptual changes are more important, but he does not deny the importance of social factors in the development of scientific knowledge. "Omitted is discussion of the *social* context of scientific change. I do not for a moment deny that social factors are important in the development of scientific knowledge; the relation between them and cognitive factors (...) I also omit discussion of non-scientific conceptual revolutions."²⁴

For Thagard, even if scientists act moved by personal interests as success or fame, they must present results to the other members of the scientific community in terms of their theoretical and experimental worth. He recognizes the existence of social factors in the advancement of science but he gives more importance to the conceptual change. "My cognitive account of conceptual change and theory acceptance is obviously not intended to be the whole story of scientific development, but it shows that a purely sociological story would never do either. I am certainly not claiming that the sociology of science *reduces* to the psychology of science; explanation can fruitfully proceed at both levels."²⁵

Therefore, three elements make Thagard different from Kuhn: psycho-sociological conversion, the preeminence of sociological explanation of conceptual change, and the stress of language in the understanding of scientific revolution in terms of translation. He refuses (then) the pure subjective conception of conceptual change.

Thagard considers that previous theory and new theory always share the rational element, also when the scientific change is radical; the modifications can include some aspects of conceptual *continuity* and overlap with the new focus and then, there are objective bases that allow a comparison between them. Therefore the growth of scientific theories is a consistent activity. On the contrary, the consequence that we can follow from the premises of Kuhn, especially from his initial stage, is to situate methodology of science in an unstable place more as a modulated phenomenon by the psycho sociological streams, as it happens in the election among incompatible paradigms, than as a consistent activity.

It is necessary to insist that scientific revolutions are largely conceptual, and this is compatible with the recognition that they are accompanied by deep changes in the kind of practices that they carry out. Science has not a merely theoretical dimension, social factors also affect it. Then, after a revolutionary change, there are different laboratory and experimental practices. This is something that can be observed in the changes of the research on neurodegenerative diseases where the study paradigms overlap.

A scientific revolution implies a conceptual innovation that must be appropriate for the real process, and it involves a structural change in a discipline. But the key must be in the ability of science of reviewing itself more than in the social environment where scientific activity is developed. In this way, the conceptual change insists on the new structural proposal of a scientific field.²⁶

²⁴ THAGARD, P., *Conceptual Revolutions*, p. 10.

²⁵ *Conceptual Revolutions*, p. 113.

²⁶ Cf. GONZALEZ, W. J., "Las revoluciones científicas y la evolución de Thomas S. Kuhn," pp. 15-103.

In this context, there are several important aspects:

- The extension of public knowledge/ignorance of science and technology.
- More effective ways of communication with the public about scientific and technological issues.
- The way as public thought about science and technology had more support.
- Medicine has been the “science-star” this century and usually the attitude to science has been more positive in the past.
- It seems that knowledge is not a key factor for public acceptance of science and technology. Citizens with knowledge become consumers that distinguish scientific experts.
- It is important to notice that a remarkable difference exists between those aspects that people simply do not know about science and those that they choose, without any prejudice or good reason, and deny. Particularly in ecology, and in the fields of health, the members of the public can argue, for example, that scientific counsel has been wrong in the past about safety of pesticides, or the harm of CFCs, etc.²⁷

The role played by the mass media in science and technology is considered really important, because journalists are usually the only contact that public has with the researchers and laboratories after schooling. Approximately, 90 per cent of the scientific and technical information is provided by mass media, as it is said in a research conducted by the Royal Institution of Great Britain’s Science Media Center, 2002.²⁸ For this reason, journalism increases the ability of the audience to evaluate science policies or decide rationally, but it can also guide the public wrongly. The public is guided by the opinions of the experts selected and/or interpreted by, the media.²⁹ These ideas, in democratic systems are translated into policies and, therefore, they affect the funds of some researches and they have an influence on the methodology applied.

In addition, communicating science in the mass media exerts an influence on the impact of journals, as Phillips, Kanter, Bednarczyk and Tastad demonstrate in a recent study that compares the number of references in the *Science Citation Index* of articles in the *New England Journal of Medicine* that were treated in *The New York Times*, with a similar number of articles not covered by the newspaper.³⁰ They also elaborate a comparison during three months when the *New York Times* was on a strike, but it continued preparing an edition which was not distributed.

Journal articles that appeared in *The New York Times* received a disproportionate number of quotes in each of the ten years after their appearing in the newspaper. The effect was stronger the first year after the publication, when they registered a 72.8 per cent more of scientific quotes than articles published during the strike; newspaper articles during this period were not more quoted than the others. Then they demonstrate that media coverage of medical research in

²⁷ Cf. YEARLEY, S., *Making Sense of Science*, *passim*.

²⁸ See MORENO, C., “La información científico-técnica,” in FERNANDEZ DEL MORAL, J. (ed.), *Periodismo especializado*, Ariel Comunicación, Madrid, 2004, pp. 239-261.

²⁹ Cf. GAMSON, W. A. and MODIGLIANI, A., “Media Discourse and Public Opinion on Nuclear Power: A Constructionist Approach,” *American Journal of Sociology*, v. 95, n. 1, (1989), pp. 1-37; NELKIN, D., *Selling Science. How the Press Covers Science and Technology*, Freeman and Company, New York, 1995.

³⁰ See PHILLIPS, D. P., KANTER, E. J., BEDNARCZYK, B. A. and TASTAD, P. L., “Importance of the Lay Press in the Transmission of Medical Knowledge to the Scientific Community,” *New England Journal of Medicine*, v. 325, (1991), pp. 1180-1183.

general newspapers amplify the transmission of medical information in scientific literature in the community of researchers:

“Our evidence suggests that a lay publication may serve as one of these filtering mechanisms, even for scientists. This effect seems to persist for at least 10 years after a *Journal* article appears. It is not certain whether other lay media (e.g. news magazine and broadcast news programs) also function as filters of information derived from medical research, and whether the use of such lay filters prompts some scientists to overemphasize certain medical articles and deemphasize others.”³¹

Some years later, Kiernan obtained coherent results with the *Publicity hypothesis* that was formulated by Phillips. Kiernan regards that research covered by newspapers like *The New York Times* had then higher quotation index in the scientific field. “Breaking news coverage by twenty-four daily newspaper of articles from the *Journal of the American Medical Association*, *Nature*, and *Science* was associated with more frequent citations.”³² The 563 articles that were published at least in one newspaper or broadcasted on a TV Channel which registered a mean of 116.46 quotes in comparison with the 2,092 articles that were not covered and were quoted a mean of 90.52 times.

From this conception of the advancement of science influenced by social factors, this study aims to analyze the epistemological and methodological problems in the research about neurodegenerative diseases with a mixed methodology. On the one hand, with a purely descriptive approximation of the main advances that, from the point of view of the basic and applied science, has been developed in the chosen decade, 1996-2006. This period has been selected because it contains a milestone considered crucial and it is the discovery of neurogenesis and the following jump into the public opinion of neural stem cells, especially remarkable from 2001 in United States and in Spain.³³ Since this year, the American and Spanish Congresses begin debating about public funds for research on embryonic stem cells that were presented as a hope for curing neurodegenerative diseases like Alzheimer’s and Parkinson’s.

To study the scientific micro media Pubmed and ISI Web of Science data bases have been used and several searches with keywords performed for the period from 1996 to 2006. The thesaurus for Pubmed included in text “neurodegenerative,” and then “neurodegenerative.” “Alzheimer” and “Parkinson” with “stem cell;” and “neurodegenerative” specifying “neural stem cell” and “embryonic stem cell.” For ISI Web of Science, the searches were performed with the keywords “embryonic stem cell*,” “adult* stem cell*,” “hematopoietic stem cell*,” and “umbilical cord stem cell*” in “English Language” and “Title/Topic” which followed indications of precedent studies.³⁴

To evaluate the impact that neurodegenerative diseases have had in Spanish press several searches were performed using the web databases of *El País* and *ABC*. These newspapers

³¹ PHILLIPS, D. P., KANTER, E. J., BEDNARDCZYK, B. A. and TASTAD, P. L., “Importance of the Lay Press in the Transmission of Medical Knowledge to the Scientific Community,” p. 1183.

³² KIERNAN, V., “Diffusion of News about Research,” *Science Communication*, v. 25, n. 1, (2003), p. 3.

³³ Cf. NISBET, M. C., BROSSARD, D. and KROEPSCH, A., “Framing Science: The Stem Cell Controversy in the Age of Press/Politics,” *Harvard International Journal of Press/Politics*, v. 8, n. 2, (2003), pp. 36-70.

³⁴ Cf. NISBET, M. C., BROSSARD, D. and KROEPSCH, A., “Framing Science: The Stem Cell Controversy in the Age of Press/Politics,” pp. 36-70.

were selected because they represent the extremes of the ideological spectrum from 1996 to 2006. We have searched for the most frequent quoted diseases in mass media registered as neurodegenerative diseases by the Health and Consumption Department of the Spanish Government.³⁵ Keywords “Parkinson,” “Alzheimer,” “Esclerosis Lateral Amiotrónica” and “Corea de Huntington” were used in *El País* between quotation marks and with the boolean operator AND in *ABC* which produces the same effect. Texts that dealt with “stem cell” or “mother cells” in *ABC* and *El País* were also selected with the same procedure and separated from those that included the diseases mentioned before.³⁶ Repetitions, captions, summaries and letters to the editor were eliminated. In the text files, we have selected “Alzheimer,” “Parkinson,” “Esclerosis lateral Amiotrónica,” “Corea de Huntington” in the 2,481 journalistic articles that treated stem cells with the function “search words” of the software Microsoft Word and have eliminated repetitions.

The searches have been made with the terms “mother cell” and “stem cell.” In these expressions, the linguistic transformation happens only in Spanish and “mother cell” is the one that most appears in mass media and the most employed nowadays, also among Spanish-speaking researchers. However, it comes from a wrong translation of the English expression which is “stem cell.” Taking into account that English language is the most used in Science, “mother cell” is a deviation. So Lopez Guerrero says that will be more appropriated to talk about “stem cells” and not about “mother cells.”³⁷ And Dr. Juan Ramon Lacadena, Chief of the Genetic Department of Complutense University in Madrid, confirms that “stem” means “trunk,” “log,” but never “mother.”³⁸

Other scientists say the same and they indicate that the term “mother cell” causes expectations that are absent from the term “stem cell.” This is the reason for its greater presence in the media. “The English translation had been precise, exact (...) ‘stem cells,’ someone introduced ‘mother cells’ or ‘mothers cell.’ Both terms are horrible grammatically speaking, but it is impossible to talk wherever without saying ‘mother cells,’ because if we say ‘stem cells’ it is possible that someone turn off the television. By contrast, if someone talks about ‘mother cells’ the programme will have higher audiences, because is understood as something interesting.”³⁹

3. RESULTS

Figure 1 is very illustrative about the values obtained in the content analysis of the journalistic articles and in ISI Web of Science.⁴⁰ The expression “mother cell” is the most used in more than

³⁵ Cf. MINISTERIO DE SANIDAD Y CONSUMO, “Enfermedades hereditarias y degenerativas del Sistema Nervioso central,” in <http://www.msc.es/estadEstudios/ecie9mc/webcie9mc/webcie9mc.htm> (access on June 2, 2008).

³⁶ “Mother cell” is a translation of “célula madre,” a Spanish special expression for stem cells.

³⁷ Cf. LOPEZ GUERRERO J. A., *Células madre: La madre de todas las células*, Hélice, Madrid, 2003, p. 14.

³⁸ Cf. LOPEZ GUERRERO J. A., *Células madre: La madre de todas las células*, p. 14.

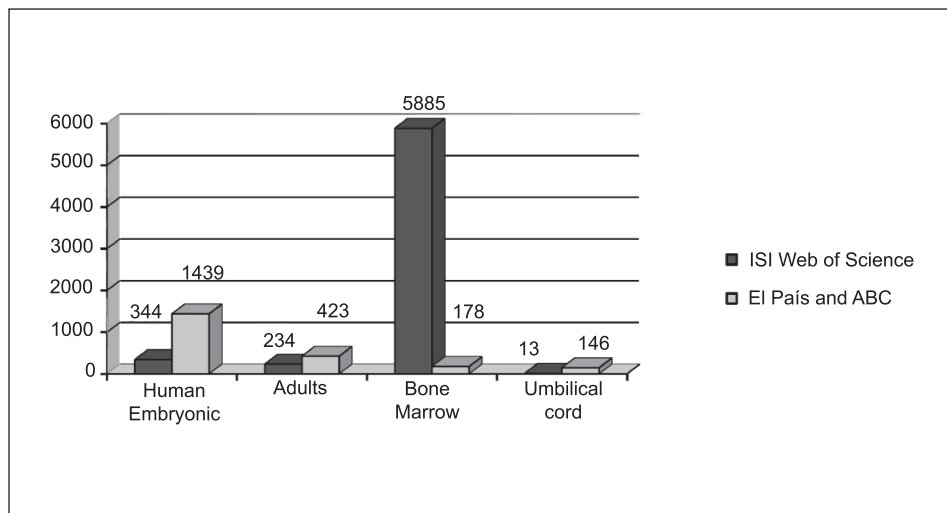
³⁹ DE LORENZO, V., CUEVAS, P., NOMBELA, C., SÁNCHEZ AYUSO, M. and RAMÓN VIDAL, D., “La manipulación genética de los seres vivos: Tecnología científica y debate social,” in NOMBELA, C. (ed.), *Retos de la sociedad biotecnológica. Ciencia y Ética*, Fundación para el Análisis y los Estudios Sociales, Ávila, 2004, p. 151.

⁴⁰ Cf. RODRIGUEZ LUQUE, C., “Research Note: Tratamiento periodístico de las ‘células madre’ desde la perspectiva del Framing. *El País* and *ABC* (1996-2006),” *Doxa Comunicación*, v. 7, (2008), pp. 165-171; NISBET, M. C., BROSSARD, D. and KROEPSCH, A., “Framing Science: The Stem Cell Controversy in the Age of Press/Politics,” pp. 36-70; and RODRIGUEZ LUQUE, C., “Tratamiento periodístico de las ‘células madre.’ Un análisis desde la perspectiva del Framing (*El País* y *ABC*, 2002),” in VV. AA., *Prensa y Periodismo especializado 4*, Asociación de la Prensa de Guadalajara, Guadalajara, 2009, pp. 197-208.

60 per cent of the journalistic texts. Also, it can be said that the specification “adults” is more a label assigned by mass media than used by researchers, because “adult stem cells” are present in 17 per cent of the press articles while in science the proportion is 2.88 per cent. Researchers prefer to be more specific by mentioning the source of stem cells, those hematopoietic stem cells are the ones from the bone marrow (7.2 % in press; 72.48% in science).

If we take into account one of the conceptual revolutions mentioned in the chapter before, specifically the one about the plasticity of adult stem cells their ability to regenerate different tissues from the ones which they are usually part of, the number of journal articles referring to hematopoietic stem cells is not surprising, because they are the easiest to obtain, to use and they have the best availability. Because, in the usual scientific jargon, when investigators talk about hematopoietic stem cells, it is understood what in press generally is labeled as “adults.”

Figure 1. Source of Stem Cells in ISI Web of Science / *El País* and *ABC* (1996-2006).

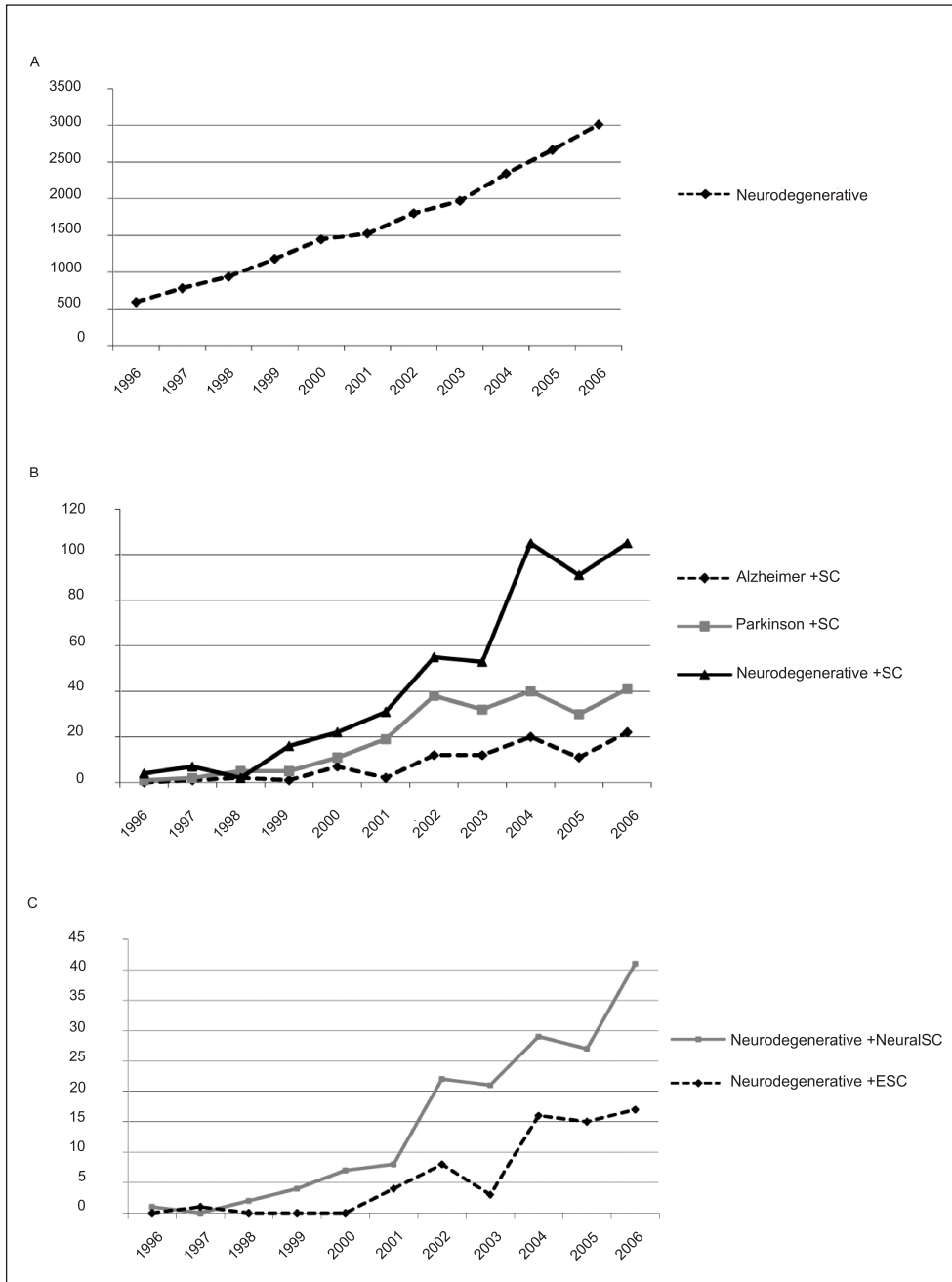


Source: Own elaboration.

Other results which depict (also) the divergences in journalistic and scientific arena are the searches performed in Pubmed (as we have mentioned before, this is one of the most used databases of scientific journals). The publications that contained the term “neurodegenerative” experienced an important increase in the analyzed period (Fig 2A). If we added as a restrictive criterion in the search “stem cell” with “neurodegenerative,” the time course was similar to the general figure (Compare Fig (b) 2A and 2B). Finally, if we included the additional presence of “neural stem cell” or “embryonic stem cell” there is a clear difference in favor of the first group.

It is evident that the analysis can be biased in some way and, therefore, it is possible that some non-pertinent articles appear in both groups, but with no doubt, the scientific interest, represented by the number of articles related to both terms, is closer to the neural stem cell, i.e. adults.

Figure 2. Neurodegenerative Diseases in PubMed (1996-2006).

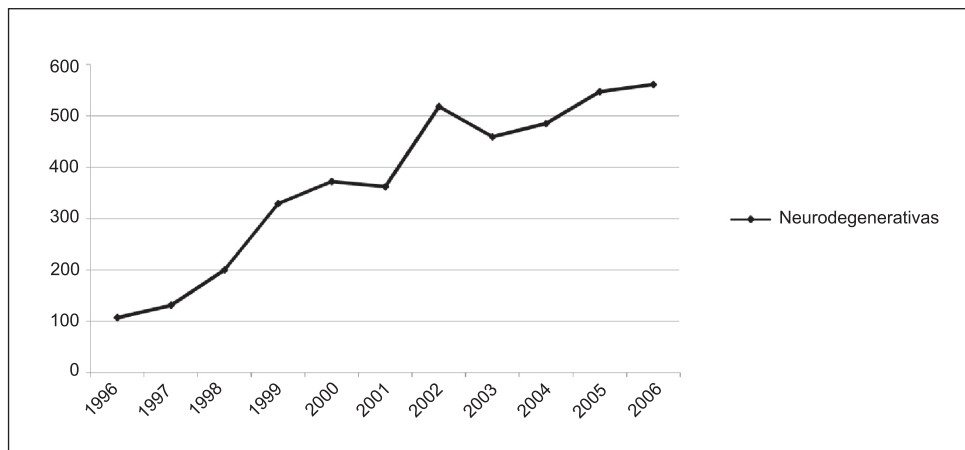


Source: Own elaboration.

The historical evolution of the events can be followed in the mass media, at the moment that sociopolitical positions emerge associated to the scientific advances. On the one hand, the ethical conflict in the use of embryonic stem cells appears and, on the other, the necessity to inform about the advances in neuroscience related to these very prevalent diseases.

After searching in the web databases of *El País* and *ABC* the neurodegenerative diseases mentioned, the distribution throughout the decade on a yearly basis is presented in Figure 3:

Figure 3. Neurodegenerative Diseases. *El País* and *ABC* (1996-2006).



Source: Own elaboration.

Broadly, an increasing trend of this issue is perceived in the press. If in the first moment, the figures slightly rise above one hundreds of texts, 107 in 1996; the numbers increase to above five hundred texts in 2002 (518 texts), this quantity keeps (more or less) fluctuating until 2006 with a minimum not below 450 texts in 2003 and 2004 (459 and 485 respectively).

As can be seen in Figure 3, there is a peak in 2002 which can be related to the remarkable presence of stem cells in the press, because that year, there were two main discussion foci: the debate about the Sixth Framework Programme of Research in the European Parliament (with the result of a moratorium specially dedicated to these cells to evaluate the ethical implications of research on embryos). Another focus is located in the Spanish Parliament where the permission for research on embryos is also discussed, especially with reference to embryonic stem cells.⁴¹

Sorted out by diseases, the most covered in both newspapers are Alzheimer's with 1052 texts in *El País* and 1022 in *ABC*, followed by Parkinson's with 898 texts in the paper owned by Prisa and 608 texts in *ABC*. Amiotrofic Lateral Sclerosis and Huntington's chorea received much less attention by the media. They always register quantities below twenty texts.

Media coverage of neurodegenerative diseases has increased especially from 1998-1999. These are the years, as was explained before, of the introduction of a new epistemic and methodological paradigm of study which coexist with the one before, the discovering of adult brain neurogenesis

⁴¹ Cf. ADROVER, T., LUJAN, J. L., REVUELTA, G. and DE SEMIR, D., *Cél.lules mare: La petjada mediàtica. La comunicació social sobre les cèl.lules troncal a la premsa espanyola (1997-2004)*, Fundació Víctor Grifols i Lucas, Contents of a research project, Barcelona, unpublished.

in human beings. This advancement has been also covered by the newspapers and the journalists have connected stem cells, especially embryonic stem cells, with the possibility of a treatment for Parkinson's and Alzheimer's diseases.

In order to visualize this relationship, we have selected from the total of the texts obtained from the web databases of the papers with "mother cells" and "stem cells," those ones which included the terms of the analyzed diseases. Specifically, from 2,481 texts in *El País* and *ABC*, 402 connect these cells to neurodegenerative diseases. It is not until 1998 when both topics appear together. In fact, the growing presence of the term "mother cells" in the newspapers starts from 1999 in Spanish press and also in North American press.⁴² This is also the year when the presence of cell regeneration in adult brain is discovered (i.e. neurogenesis), a scientific milestone with a remarkable importance in the methodological study of neurodegenerative diseases.

In addition, the Spanish press covers this event, as we can see in the texts published in *El País*. The problem was yet defined in the way of regulating (by a chemical or biochemical process) the activation/proliferation of the cells. This problem is yet unsolved nowadays.

Nisbet, Brossard and Kroepsch consider that the increase of media attention coincides with the potential of the issue to be framed in dramatic terms. In the case of stem cells, the peak was reached when the events were framed in terms of political strategy/conflict and "ethics/morality."⁴³ However, in Spanish coverage, the peak is reached between 2002 and 2004 and the more frequent frame of the articles is "political strategy" in 46.6% of the 2,841 texts and "ethics/morality" represents only 7.3 per cent.⁴⁴

The arguments for media coverage of the news related to stem cell research which shows the media analyzed, are clearly influenced by the sociopolitical context of Spain at this time, therefore, it is considered relevant to dedicate some lines to remember the main historical events.

Sociopolitical Chronology 2002-2004

- 2002 and 2004: The debate about the permission of researching on embryos is moved to the self governing regions of Spain governed by the Socialist Party as for example Andalucía and others like Valencia or Cataluña. They want to head the research on embryonic stem cells.
- October, 2002: Andalucía allows a scientist to research on human embryos and this decision is supported by a Popular Initiative of 1.3 million(s) of signatures of diabetics.
- October, 2003: Government of Andalucía announces the creation of the first Spanish Bank of stem cells. National Government feels invaded in its competences and lodges an appeal to the Constitutional Courts about the Regional Law of Embryos. Then the Parliament of Andalucía decides to appeal to the Constitutional Courts because of the modification of the Artificial Reproduction Law.

⁴² See ADROVER, T., LUJAN, J. L., REVUELTA, G. and DE SEMIR, D., *Cél.lules mare: La petjada mediàtica. La comunicació social sobre les cèl.lules troncales a la premsa espanyola (1997-2004)*, unpublished; NISBET, M. C., BROSSARD, D. and KROEPSCH, A., "Framing Science: The Stem Cell Controversy in the Age of Press/Politics," pp. 36-70; and JOHNSON, J. A., "Stem Cell Research," *CRS Report for Congress*, August 10, 2001, Congressional Research Service, Washington, D.C.

⁴³ Cf. NISBET, M. C., BROSSARD, D. and KROEPSCH, A., "Framing Science: The Stem Cell Controversy in the Age of Press/Politics," pp. 36-70.

⁴⁴ Cf. RODRIGUEZ LUQUE, C., "Research Note: Tratamiento periodístico de las 'células madre' desde la perspectiva del Framing. *El País* y *ABC* (1996-2006)," pp. 165-171.

- March, 2004: The President of the Government changes the legislation. Andalucía will have a centre for stem cell research. The Executive allowed research on embryonic stem cells (Val 1 and Val 2) in Valencia and signed agreements with the regions of Cataluña and Andalucía.
- November, 2004: Spanish Government proposes an organism to centralize the research on stem cells, the National Bank of Cell lines in Granada and it allows definitely research on embryos with a Royal Decree. The Executive announces that therapeutic cloning will be passed if there is enough social agreement.

Throughout this political debate, the mass media discussion was polarized to embryonic stem cells more than a half of the articles about stem cells in general (58%, 1,439 texts), with less attention to other sources of stem cells like adult ones (17%) or from the bone marrow (7,2%) that, however, are more present in the scientific arena (See Fig. 1).⁴⁵ There is a remarkable dominance of embryonic stem cell on media coverage that is also noticed by readers, as Enrique Costas describes in a letter to the editor published in *El País* with the title “Stem cell.” He quotes an American bioethicist called Daniel Callahan who is also conscious of the silence about other alternatives which produces the polemical permission for research on embryos:

“Sometimes, I have the impression that if embryonic stem cells are not used in research, there is not any hope to obtain a treatment for a lot of deadly diseases. This is simply not true, instead (of) this argument is usually employed by their more enthusiastic proponents, who do not mention the scientific limitations of research: the research on embryonic cells will last for a long time, it will be expensive and, after that, it is possible that it would not achieve good results (...). Some statements, however, lead the public and often the patients to conclude that the experiments will be finished soon or that they will be certain to be successful.”⁴⁶

Also Bellver appreciates that adult stem cells have not reached the same level of media attention than embryonic stem cells: “Oddly, the advancement in the isolation and the therapeutical use of adult stem cells has never reached, by far, the same relevance as the information related to embryonic stem cells.”⁴⁷

4. CONCLUSION

The results herein clearly show the coincidences and disparities between the two areas studied: science and mass media. Assuming the inseparability of both environments, it could be confirmed that they exert mutual influence on each other. It is logical to consider that journalists should be aware of scientific discoveries and quick to inform the public about them. However, in Spain, it is clear that the criteria used to consider what is newsworthy goes in the opposite direction to scientific advancement, prioritizing always embryonic stem cells. This overwhelming prevalence of embryonic stem cells in the press could be interpreted as a clear attempt by the mass media to influence scientific researchers. Research on the press by means of counting, cataloguing, categorizing and *Framing*, versus scientific publications data bases

⁴⁵ Cf. RODRIGUEZ LUQUE, C., “Research Note: Tratamiento periodístico de las ‘células madre’ desde la perspectiva del *Framing*. *El País y ABC* (1996-2006),” pp. 165-171.

⁴⁶ COSTAS, E., “Células madre,” *El País*, July 4, 2002, p. 13.

⁴⁷ BELLVER CAPELLA, V., *Por una Bioética razonable. Medios de Comunicación, Comités de Ética y Derecho*, Comares, Granada, 2006, p. 21.

clearly demonstrates that the latter have an increasing interest in adult stem cells with special emphasis on those cells of easier access and management, hematopoietic, even for research in neurodegenerative diseases, in view of their plasticity.

There is a clear influence on the mutual relationships between both areas in North America and Spain. It is plausible that the impact of scientific findings on the mass media and vice versa is apparently higher and more rigorous in North America than in Spain.

Finally, the discovery of the existence of adult neurogenesis in humans is probably the conceptual revolution that will drive the methodological aspects of the research on neurodegenerative diseases in the 21st century.

It is evident that this change is linked to other discoveries and the subsequent penetration in knowledge of the concepts, such as the mechanisms of cell death (e.g. apoptosis), that tends to take place in health sciences. The new discovery overlaps with former paradigms and we do not know whether the older theories will survive or not.

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IV

Medicine and Conceptual Change

- 7. Conceptual Change in Medicine and the Life Sciences
- 8. Conceptual Change in Medicine: Explaining Mental Illness

CONCEPTUAL CHANGE IN MEDICINE AND THE LIFE SCIENCES

Matti Sintonen

1. INTRODUCTION

Scientific inquiry is rational activity which aims at two types of goals. First, there are the cognitive goals determined by the desire and need to understand the world. Scientists, therefore, are in the business of describing and explaining phenomena by help of models and theories. Secondly, sciences aim at practical utility and control. As many proponents of early modern science held, to think that knowledge should be pursued just for the sake of this knowledge, for purely intellectual reasons, would be morally perverse. Natural philosophers or scientists ought to put their knowledge for practical benefit: in view of their knowledge they are also in the position to give advice and guidance.

What is true of science and inquiry in general is true of the life sciences and medicine in particular. Both fields provide fascinating intellectual challenges, and both are important sources of practical benefit. How we understand life (as against the non-living world) or health (as against illness) have always been a central concern in our common-sense view of ourselves as actors and agents. Matters of life and health have also been pervaded by religious beliefs and practice, a fact that explains why purely naturalistic accounts of, say, the origins and development of life have encountered such vehement resistance and why changes in the way we conceptualize health are cognitively and emotionally coloured, as Paul Thagard in particular has pointed out.¹

Our knowledge of life and health has gone through a number of conceptual upheavals since their inception in Greek thought some 2500 years ago. Conceptual change comes in degrees: there are relatively minor alterations such as introducing new instances of a concept, medium-size changes such as coining new concepts, and revolutionary upheavals that affect classifications and ways of organizing conceptual hierarchies. Paul Thagard has offered an important 9-stage way of classifying conceptual changes that builds on the notion that concepts couched in terms of mental representations.²

This paper is not a historical survey of conceptual change, nor do I want to suggest a rival ontology to those already in existence. Rather, I wish to provide a limited but natural complement to available accounts in terms of what I will call the *interrogative view of inquiry*. Inquiry and knowledge-seeking more generally are here seen as question-answer processes. The goals of

¹ Cf. THAGARD, P., "What Is a Medical Theory?," in PATON, R. and MCNAMARA, L. A. (eds.), *Multidisciplinary Approaches to Theory in Medicine*, Elsevier, Amsterdam, 2006, pp. 47-62.

² Cf. THAGARD, P., *Conceptual Revolutions*, Princeton University Press, Princeton, NJ, 1992. See also THAGARD, P., "The Concept of Disease: Structure and Change," *Communication and Cognition*, v. 29, (1996), pp. 445-478, and THAGARD, P., "What is a Medical Theory?," pp. 47-62.

science, understanding and providing guidance to action by help of this understanding, can be attained through questions that arise against the background of cognitive expectations and practical concerns. The novelty of the interrogative perspective given here is in the recognition that revolutionary conceptual change can pertain, on one hand, to the *types of questions* that can be asked but on the other hand to the *nature of the questioning procedure itself*.

Extant models of conceptual change focus on the former aspect: a revolution may occur when some types of questions become obsolete (“the question does not rise”) or when new types of questions become possible. For instance Nicholas Jardine has suggested that in order to understand how the sciences have evolved one must focus, not on the doctrines that are answers but on the “the ways in which new questions are brought into being and old ones dissolved.”³ He gives an account of how questions surface as candidates for serious pursuit and examination within particular scientific communities and specific times. Thus the scenes of inquiry are in the process of as formation, transformation and dissolution all the time: questions which in one scientific and cultural setting are locally real may be incomprehensible in another one. His example is early German *Naturphilosophie*, and especially Lorentz Oken’s puzzling *Lehrbuch der Naturphilosophie*. Oken was a highly respected naturalist who gave an extraordinary detailed classification of the three orders of nature. Yet, by our lights, his proposals, formulated some 200 years ago, are outright bizarre: “The organic must be a vesicle because it is the image of the planet;” “The animal kingdom is but a dismemberment of the highest animal, man.”⁴

In Jardine’s view these pronouncements are so far from our way of seeing the world that Oken’s questions are, for us, unreal and not just uninteresting. The interesting question is: how come Oken’s books were so widely discussed and taken seriously? The short answer is that from the prevailing Blumenbach-Kant point of view these opinions were well within the mainstream thought. The Kant-Blumenbach way of tallying empirical laws with the grand teleological requirements of reason and understanding opened up an entire range of new questions (and excluded others as illegitimately metaphysical), and resulted, through a series of transformations, to the scene on which Oken acted.

I shall first outline the interrogative view and its philosophical motivation (2) and then turn to one important type of conceptual revolution in our view of natural, viz., the view that we should address our questions to Nature directly. This revolution did not concern the formation of new concepts, or with a reshaping of an entire conceptual network, but rather had to do with what counts as a legitimate source of knowledge. The early modern metaphors of Reading the Book of Nature (3) and Putting Questions to Nature (4) did affect the medical and the life sciences, but on the whole they were wholesale revolutions that restructure the entire natural philosophy. With these developments in mind I shall take a fresh look at what I call Darwin’s interrogative agenda (5) and the nature of the Darwinian Revolution (6). The theory of evolution through natural selection changed the scene in the study of life by opening up an entirely new terrain of questions that might be legitimately asked concerning life. Interestingly, it also turns out that Darwin also was a skilful practitioner of the interrogative method of inquiry. I shall conclude with some partly speculative notes on new revolutions waiting at the door (7).

³ JARDINE, N., *The Scenes of Inquiry. On the Reality of Questions in the Sciences*, Clarendon Press Oxford, 1991, p. 3.

⁴ Quoted from JARDINE, N., *The Scenes of Inquiry. On the Reality of Questions in the Sciences*, p. 51.

2. THE INTERROGATIVE VIEW

Take as example from medicine the case of puerperal fever. A deadly disease went rampant in Austrian hospitals (and elsewhere) killing both mothers and babies. The suspected cause was “cadaveric matter,” but this was just a label without knowledge of the nature of the disease. It took Ignaz Semmelweis, from the First Obstetric Division of the Vienna General Hospital, years to probe the available literature and suggested explanations, and it was well-nigh impossible to come up with a hypothesis that did not fly on the face of known facts or simple tests. For instance it was conjectured that mothers were terrified by the clergymen that went to the sickroom to give the last sacrament. To test this hypothesis Semmelweis ordered a change in the practice but it had no effect on the incidences of childbed fever. Similarly, it was conjectured that the deaths resulted from the rough examination procedures of foreign medical students, or were due to the position in which mothers delivered their babies (lying on their backs as against lying on their sides).

There were, however, commonsense as well as experimentally induced objections to all of these: delivery itself was rougher than the actions of the students, and a change of position had no effect. Available attempts also included “atmospheric-cosmic-telluric” influences, the food given to mothers, or the diet. However, these proposals gave no reason why incidence and mortality were higher in the First division than the Second, why they were higher in Vienna than in the surroundings, so that they failed the important test of accounting for the contrastive type of questions: “Why in the First division rather than the Second?” or indeed: “Why was the decease more prevalent in the hospitals than in the streets?”⁵

We now know that puerperal fever was caused by bacteria (most often *Staphylococcus aureus* or one of the *Streptococcus* bacteria), indeed “cadaveric matter” that was transmitted to the mothers by doctors and medical students who often had conducted autopsies before prior to minding deliveries — and without washing their hands or using chlorine or other disinfectants. The details of the story of the discovery are well-known and so are the mechanisms through which micro-organisms operate. The lesson here concerns the types of questions raised by Semmelweis and others before him, and the revolution in theory and practice that his questions initiated. Semmelweis’s view, that washing hands would (with or without disinfectant) would reduce the incidences of puerperal fever was not well received by the community. It offended the pride of practitioners and was inconsistent with the received view of diseases. It took time and the experimental work of Louis Pasteur to establish (though not to the satisfaction of all!) the germ theory of disease. But once it did, the field of medicine was open to endless analogous inquiries concerning this or that disease.

Semmelweis’s inquiry was prompted by the pressing health concern of finding the cause of childbed fever, and hence to find an answer to “Why is there childbed fever?” or “What causes childbed fever?” The noteworthy feature of the process of inquiry was that regardless of the surface form of the question there was no plausible candidate for an answer, candidate that could square with the facts. Indeed, in the earliest stages of inquiry the question was ill-defined in the sense that neither those who raised the question nor those who set out to find the answer knew exactly what sort of an answer was of the right type (more of this in section 3 below).

Semmelweis had a skilful mastery of the interrogative method of inquiry — that of asking the right question at a right time, and that of turning unanswerable big questions to answerable

⁵ For this, see LIPTON, P., *Inference to the Best Explanation*, Routledge, New York, 1991.

small ones. But before going to the details of the method, let us take a look at its pedigree. The interrogative view was the default view of inquiry in Greek philosophy from Plato's *elenchus* to Aristotle's dialectics. It has been suggested that Aristotle's account of four causes should be understood as four different types of explanatory patterns, or indeed as four different ways of answering the question "Why?" And of course we owe to Aristotle the very cornerstone of what inquiry proper is all about, viz., the principle that differentiates between *knowing that* something is the case from *knowing why* it is the case. An inquiring mind cannot settle for mere knowledge that, say, radiation causes developmental disorders or that smoking causes cancer. Rather, as Aristotle observed, man by nature seeks knowledge and the proper way of fulfilling this built-in desire is through knowing why.

The interrogative view also finds independent systematic support elsewhere. Questions and answers are central to our commonsense view of our goals and means of attaining the. Raising questions, addressing them to others, looking for answers and responding to questions of others by answering are primordial modes of actions — these language games or types of speech act are the most important building blocks of our folk psychology and folk social science. Indeed, raising questions and giving answers are deeply entrenched in our cognitive capacity.

This interrogative view also accords with working scientists' self-understanding and captures a variety of scientific activities, from the search of hypotheses to test and acceptance. As I will suggest, any well-structured research project can be cast in the form of an interrogative portrayal which starts from some big initial a research questions and then proceeds to answer them by help of small questions — and indeed the way of questions has been one of the cornerstones of a methodical way of knowledge seeking.

Although the Greeks were the founding fathers of philosophy and science in the form we know them we can go a bit deeper into the varieties of questions. This is all the more important since doing so enables us to illustrate how deep conceptual changes reflect in the types of questions that have been thought intelligible or worth raising — and in the types of answers that have been considered admissible.

The first type of questions that I wish to distinguished are what (erotetic) logicians call wh-questions. These are the wh-questions, viz. where-, who-, when- etc., questions that receive singular terms as answers. These questions also include how-many questions in their different varieties: how many centimeters, how many seconds, how many amperes, etc. The second type of questions are propositional questions that take complete propositions as answers: one can know *that* smoking causes cancer, or one can know *whether* a particular cancer was caused by smoking or radiation (though singular causal claims may be difficult to assess), or one can know *why* smoking causes cancer.

From the point of view of the scientific procedure there is a great difference between ill-defined and well-defined questions. Some what-questions, how-questions and why-questions signal puzzles and require complicated causal stories or explanations for answers. The difference is often not visible in linguistic surface form (in the sentence used to express the question) but can only be revealed by focusing on the deep structure of the epistemic state that an inquirer finds herself or himself in.

The crucial feature of well-defined questions is that here both the questioner and the answerer know what sort of an answer is of the right type. This means that there is available conceptual equipment that can serve as a basis of categorizing potential answers. Here the questioner knows, when putting the question, what counts as an answer. She or he is perhaps able to enumerate all

possible substitution instances, as in yes-no- (and which-) questions: here the answerer's task boils down to the choice of one of the displayed alternatives. Or the questioner knows precisely what types entities would count as direct answers, and is (usually) fulfilled by wh-questions. An answer to a what color-question must specify a color, an answer to a who-question a person, and an answer to a where-question a place to count as an answer of the right type. One can ask where the hippocampus is, when the first reptiles evolved, or how many pairs of legs insects have. Justified answers to these questions may involve complex arguments, but the questions themselves have well-defined ranges of potential answers: only particular anatomic locations, or paleontologic periods, or numbers count. The context may make it clear that the questioner has a very narrow range of candidate answers. There may of course be further contextual demands which still narrow down possible substitution instances, but the general observation holds: mere knowledge of language and of the area of discourse suffices to guarantee that both the questioner and the answerer know precisely what would count as an answer.

The suggestion, from the interrogative point of view, is that of deep conceptual change often is signalled by changes in the conceptual apparatus used for classification. Philosophically the most intriguing debates in physics as well as the life sciences hinge on the possibility that questions that were considered well-defined may turn out not to be so: the strange world of quantum mechanics does not allow localisation in the way our commonsense view of objects requires (so that, strictly speaking, the question, say, of the exact location of a particle may not arise). In the life sciences the near eternal nature-nurture debate allows questions such as "Is a particular feature or behavioural patterns P of an organism O due to the genes or the environment?" may likewise turn out to be a false one (at least for some P's and O's).

3. READING THE BOOK OF NATURE

Let me now turn to the first example of conceptual revolution that I advertised in the beginning. Supposing that knowledge-seeking is a question-answer process, where should the questions be directed at? According to the new natural philosophers (critiques of Aristotelian science) the science of the schoolmen as well as the humanists who aimed at rescuing classical wisdom suffered from a fatal inadequacy. They took it for granted, namely, that the ancients (Greeks, mostly) had a correct view of man and nature, and that we only need to study classical documents to find out the truth. The task many humanists found themselves facing was to purify the received and but only alleged wisdom from misinterpretations that had accrued during centuries. The Greek notion of knowledge was not geared to exploring the depths of the unknown but rather towards explicating and transmitting to the generations to come what was already known and recorded in the classical texts. To put this view of knowledge (necessarily somewhat simplistically): the questions were to be addressed to existing sources of knowledge, that is, to established texts. This of course needed hermeneutic interpretation aimed to finding out the true meaning of the texts. And one important hidden commitment is precisely here: the idea that inquiry is to read the books of the ancients, especially Aristotle's (or the Bible, or indeed both).

In medicine and the sciences of life (biology pretty much a newcomer, conceptually) one of the early signs of discontent was Theophrastus Phillipus Aureolus Bombastus von Hohenheim, better known as Paracelsus. Paracelsus has been regarded as one of the transition figures from magic and mysticism to modern natural philosophy in that he not only developed the use of

knowledge of chemistry in the understanding of human health but also pioneered a new view of the scientific method — the way one should proceed. He refused to accept what was handed over to him and his contemporaries in tradition and outright hearsay, and insisted that the only source of truth was nature itself. And nature revealed her secrets in observations and experiment.

This is how Paracelsus describes his philosophy concerning Galen and the ancient authorities (*The Hermetic and Alchemical Writings of Paracelsus*, vol. 1, p. 21):

“I did embrace at the beginning these doctrines, as my adversaries (followers of Galen) have done, but since I saw that from their procedures nothing resulted but death, murder, stranglings, ankylosed limbs, paralysis, and so forth, that they held most diseases incurable... Therefore have I quitted this wretched art, and sought for truth in any other direction. I asked myself if there were no such thing as a teacher in medicine, where could I learn this art best? Nowhere better than the open book of nature, written with God’s own finger.”

And Paracelsus elaborates (*The Life and Doctrines of Philippus Theophrastus*, p. 27):

“I began to study my art by imagining that there was not a single teacher in the world capable to teach it to me, but that I had to acquire it myself. It was the Book of Nature, written by the finger of God, which I studied not those of the scribblers, for each scribbler writes down the rubbish that may be found in his head; and who can sift the true from the false? My accusers complain that I have not entered the temple of knowledge through the legitimate door. But which one is the truly legitimate door? Galen and Avicenna or Nature? I have entered through the door of Nature: her light, and not the lamp of an apothecary’s shop, has illuminated my way.”

Although Paracelsus did not fully break away from Aristotelianism he did pioneer the view that later became an official doctrine through a shift of allegiance as it were: with Paracelsus and the new natural philosophy the order of allegiance was reversed: observation and experience first, then reason, and authority only after these two (and authorities only to the extent they were reliable representatives of experience and reason). Although the influence of Paracelsus soon waned these allegiances became a permanent commitment for natural scientists and medical doctors alike. Just to take one example, William Harvey took the Paracelsian request to inspect Nature directly to heart and discovered that Galen’s views were contrary to the observations of sense and therefore had to be rejected. In the beginning of Chapter I of his seminal treatise on heart Harvey writes of his motives for writing: “When I first gave my mind to vivisections, as a means of discovering the motions and uses of the heart, and sought to discover these from actual inspection, and not from the writings of others, I found the task so truly arduous ... that the motion of the heart was only to be comprehended by God.”⁶ Harvey also was an accomplished interrogationist: in the Preface he conducts his criticism of Galen in five (series) of questions that are unanswerable if the received view is adopted. Here is the first step: “Why, I ask, when we see that the structure of both ventricles is almost identical, there being the same apparatus of fibres, and braces, and valves, and vessels, and auricles, and in both the same infarction of blood, in the subjects of our dissections, of the like black colour, and coagulated — why, I say, should their uses be imagined to be different, when the action, motion, and pulse of both are the same?”⁷

⁶ HARVEY, W., *On the Motion of the Heart and Blood in Animals*, George Bell and Sons, London, 1889, p. 19.

⁷ HARVEY, W., *On the Motion of the Heart and Blood in Animals*, p. 14.

4. PUTTING QUESTIONS TO NATURE

Harvey was in fact not just reading the Book of Nature — he was rather a supporter of experimental natural philosophy — and no doubt influenced by Francis Bacon (who in fact was claimed to be one of Harvey's patients). Indeed Bacon went further by emphasizing that interpretation of nature is not just relatively passive reading but active experimentation. Bacon insisted that science begins where man begins "putting nature to the question." As R. G. Collingwood added, "scientific technique meant simply the skilful asking of questions,"⁸ a view that was later taken over by Immanuel Kant in the Preface to the *Critique of Pure Reason*. Kant emphasized, even more pronouncedly than Bacon if possible, the ineliminable role of the inquirer in the interpretation of nature. Kant insisted that when Reason approaches nature it must do so not "in the character of a pupil who listens to everything that the teacher chooses to say, but of an appointed judge who compels the witnesses to answer questions which he has himself formulated."⁹

Note the plural for questions, for it carries the implication that in issues of any consequence, those which involve secrets, Nature cannot be cornered in a single move. Experimental science is not a one-shot affair but involves planning. Nature will not easily reveal her secrets so that it is up to the experimenter to design, for each big question concerning her secrets, a series of questions that forces Nature to give an unambiguous answer. What we desire to know determines the goals of inquiry, i.e., what is worth knowing for cognitive or practical purposes. These goals manifest in and give rise to what I call *big* questions. But a closer look at Kant's proposal reveals another role for questions and answers. The paths to answers to these big questions are paved by *small* questions. Both types of questions can be graded with respect to their importance or weight, the intrinsic cognitive value an answer has for the edifice of knowledge, or the instrumental value an answer has in bringing inquiry closer to the goal.

There is a particular worry that this picture of inquiry gives rise to — and that points out to a crucial feature of modern science. Nature can only testify to what She has seen herself. The issue arises within the interrogative model as follows. Observations and experiments can be viewed as questions put to Nature because here the answerer's (Nature's) task confines to recording one of the two outcomes of a yes-no question, or one of the possible the meter readings of an apparatus (25 °C, say). The way we understand observations and experiments relies on the idea that we are in causal interaction with inert Nature, with or without intervening into its course. On this view Nature cannot offer answers of a general form because the presuppositions of general questions are beyond Nature's capacities. In interrogative terms the presuppositions of the questions that can be put to nature, i.e. propositions without which the questions do not have direct answers at all, confine to particular matters. To put it in a nutshell, one cannot ask Nature to provide an answer to a question that records an ill-defined and general puzzle. To continue the metaphor of early modern science, Nature does not understand why- and how-questions, or what-questions that do not offer well-defined alternatives from which to choose. In particular, Nature is helpless in the face of cases where the potential answers require concepts that go beyond those in which the question is phrased.

⁸ COLLINGWOOD, R. G., *Essay on Metaphysics*, Clarendon Press, Oxford, 1940, pp. 238-239.

⁹ KANT, I., *Kritik der Vernunft*, 2nd ed., Reclam, Leipzig, 1787. Translated by Norman Kemp Smith: *Critique of Pure Reason*, St Martin's Press, New York, 1968, B, pp. xiii-xiv.

This means that the questions-to-Nature view faces a dilemma and the possibility of obtaining new knowledge is at jeopardy. On the classical view of knowledge an inquirer's task was to find, in existing literature, descriptions of phenomena such as disease. But equally well, these authorities could venture explanatory answers in the form of generalizations and theories. However, if the word of authorities is not accepted as a legitimate source, how could one proceed to knowledge? More specifically, how would one tackle questions that go beyond simple observational yes-no questions and well-defined wh-questions? This is in a nutshell the systematic counterpart of the historical dilemma, since modern science, ever since it accepted hypotheses that resorted to unobservables threatened to leave the secure path of knowledge and enter the realm of speculation.

The problem of underdetermination vis-à-vis explanatory theories is still with us. But if we leave the fundamental epistemological worry, is there anything that can be said about how hypotheses could be discovered? Let us return to some examples, starting with puerperal fever already touched above. How did Semmelweis go about making his discovery? The suggestion is that Semmelweis had a general puzzle, but no solution.¹⁰ This means, among other things, that the initially very general why-question "Why is there childbed fever" was processed into more specific whether and yes-no questions. The logic of inquiry, in this case and in many others, proceeds by phrasing initially vague questions and by nurturing them into a form that can be tested through observations and experiments.

Here the big initial research question is "Why is there childbed fever" (or "What causes childbed fever?" if, as is reasonable, we are assured that a causal explanation is called for). For reasons already mentioned, there is no way this question could be addressed to Nature directly. Indeed, to ask the initial question and to expect an answer would be to commit the Fallacy of Begging the Question (although, as Hintikka has noted, this is not a fallacy of reasoning but rather a case where the rules of the interrogative game are violated.¹¹) Inquiry, finding genuinely new knowledge, would be too easy if all one needed to do was repeat the initial big question. Instead, one must approach Nature by splitting the question into subquestions that Nature is able to answer, i.e. to manageable wh-questions and yes-no-questions.¹²

The salient scientific skill is therefore that of designing a series of questions that leads from the big questions, by help of small questions, to potential answers to the big question. And to the extent experiments are questions to nature, designing such a series amounts to a design of an experimental set-up. This, in fact, was the some scientists inspired by Bacon's and Kant's method saw it. An excellent example was the Danish neo-Kantian physicist Hans-Christian Oersted's who equated the questioning procedure with that of making experiments: "To make

¹⁰ Semmelweis falls in a p-predicament in the sense of Sylvain Bromberger. Bromberger writes that a why-questions arise when a person is either in a p-predicament or a b-predicament concerning some fact. The former is the case when a person thinks that a why-question admits of a right answer but she or he can think of no non-objectionable one. The latter is the case if the question "admits of a right answer, no matter what the views of the person, but that answer is beyond what that person can think of, can state, can generate from his mental repertoire," BROMBERGER, S., "Why-Questions," in COLODNY, R. G. (ed.), *Mind and Cosmos*, Pittsburgh University Press, Pittsburgh, 1996, p. 91. See also BROMBERGER, S., *On What We Know We Don't Know: Explanation, Theory, Linguistics, and How Questions Shape Them*, The University of Chicago Press, Chicago, 1992.

¹¹ See HINTIKKA, J., *Inquiry as Inquiry: A Logic of Scientific Discovery. Selected Papers 5. Essays No. 5*, Kluwer, Dordrecht, 1999.

¹² I am not suggesting, though, that Nature always gives unambiguous answers to wh-questions or yes-no questions, See SINTONEN, M., "How to Put Questions to Nature," in KNOWLES, D. (ed.), *Explanation and its Limits*, Cambridge University Press, Cambridge, 1990, pp. 267-284.

experiments is to lay questions before nature; but he alone can do that beneficially *who knows what he should ask.*"¹³

Is there any "beneficial logic" of laying questions before nature? The 20th Century received view has been that there is no logical way of having ideas: there can be strong and weak heuristics but the role of serendipity cannot be done away with completely. Yet there are strategic principles that help in the cultivation or nurturing of big questions, as well as a straightforwardly logics of generation. One proposal comes from Andrzej Wisniewski's erotetic logic (based on multiple-conclusion logic) in which questions can serve as premises and conclusions: one can, e.g., derive a more specific question from a general one on the basis of declarative premises. His *erotetic search scenarios* also contains strategic principles for moving from question to question without actually pausing to answer every one of them when and where they arise.

Wisniewski proposal is that it often serves the purposes of inquiry better to derive a more specific question which in turn gives rise to a further question — as when an answer to the latter counts as an answer to the former. One of his examples goes as follows. If you want to find a person X and you know that X has gone to either to Paris, London, Kiev or Moscow, you might raise the four-fold whether-question "Did X go to Paris, London, Kiev or Moscow?" But addressing all disjuncts separately might be beyond possibility — Nature not being in the mood to cooperate as it were. Yet you can resort to an indirect strategy based on auxiliary information. You may be able to reason that *if* X travelled to London or Moscow *then* he could not have taken a train. By deriving further questions, again based on contextual knowledge or available background information, e.g. about X's time of departure ("When was he last seen!"), possibilities of travel ("Did he take a train in the morning?") etc., you may manage to rule out some alternatives hence to narrow the number of possibilities. These search scenarios (not to speak of their explicit logic) would take too much space to produce here, but the upshot is that they yield an answer to the initial question through a series of inferences, some of which are inferences from questions to more specific questions. The attraction of erotetic search scenarios is that they give tangible though conditional advice as to which questions to ask and when. Now there may not be any algorithmic logic for question generation but certainly erotetic search scenarios take us some way towards cashing out Oersted's insight.¹⁴

5. INTERROGATIVE AGENDAS

Another illustration of the power of the questions/answers strategy is the discovery of the theory of natural selection by A. R. Wallace and Charles Darwin. Here is, first, Wallace's condensed account as it is related in his Autobiography. He notes that Malthus's *Principles of Population* was perhaps the most important book he read, one "which twenty years later gave me the long-sought clue to the effective agent in the evolution of organic species:"

¹³ OERSTED, C., "On the Spirit and Study of Universal Natural Philosophy," in OERSTED C., *The Soul in Nature*, with Supplementary Contributions, trans. Leonora and Joanna B. Hoerner, H. G. Bohn, London, 1852. Reprinted by Dawsons of Pall Mall, London, 1966. (Emphasis added).

¹⁴ Cf. WISNIEWSKI, A., "Erotetic Search Scenarios," *Synthese*, v. 134, n. 3, (2003), pp. 389-427. See also WISNIEWSKI, A., *The Posing of Questions: Logical Foundations of Erotetic Inferences*, Kluwer, Dordrecht, 1995; and WISNIEWSKI, A., "Some Foundational Concepts of Erotetic Semantics," in SINTONEN, M. (ed.), *Knowledge and Inquiry. Essays on Jaakko Hintikka's Epistemology and Philosophy of Science*, Poznan Studies in the Philosophy of the Sciences and the Humanities, Vol. 51, Rodopi, Amsterdam, 1997, pp. 181-211.

It then occurred to me that these causes or their equivalents are continually acting in the case of animals also; and as animals usually bred much more rapidly than does mankind, the destruction every year from these causes must be enormous in order to keep down the numbers of each species, since they evidently do not increase regularly from year to year, as otherwise the world could long ago have been densely crowded with those that breed most quickly. Vaguely thinking over the enormous and constant destruction which this implied, it occurred to me to ask the question, Why do some die and some live? And the answer was clearly, that on the whole the best fitted live. From the effects of disease the most healthy escaped; from enemies, the strongest, the swiftest, or the most cunning; from famine, the best hunters or those with the best digestion; and so on. Then it suddenly flashed upon me that this self-acting process would necessarily improve the race, because in every generation the inferior would inevitably be killed off and the superior would remain — that is, the fittest would survive. Then at once I seemed to see the whole effect of this, that when changes of land and sea, or of climate, or of food-supply, or enemies occurred — and we know that such changes have always been taken place — and considering the amount of individual variation that my experience as a collector had shown me to exist, then it followed that all the changes necessary for the adaptation of the species to the changing conditions would be brought about ... The more I thought over it the more I became convinced that I had at length found the long-sought-for law of nature that solved the problem of origin of species...¹⁵

Conceptual changes come in degrees. As Paul Thagard has argued, the most radical kind of conceptual change involves changes that bring about new principles of classification. One of his examples was the Darwinian revolution through natural selection which changed the way species were understood: Before Darwin classification was mainly in terms of similarity, as a result of Darwin's theory there was a more fundamental mode of classification in terms of common origin.¹⁶ I shall deal with this from a somewhat different aspect below, but the point remains. In view of Darwin work part of the community of natural historians and scientists, those who adopted the historical or evolutionary perspective, came to develop a taxonomy based on descent and not just similarity.

As to Darwin, his method and his own view of his method are gratifying objects of study, for rival reconstructions can be substantiated by reference to his publications and notes. Darwin kept extensive record of the emergence of his ideas in his Journal, Notebooks, memoranda, and loose pieces of paper. He claimed to be a Baconian: "I worked on true Baconian principles, and without any theory collected facts on a wholesale scale..."¹⁷ However, this is far from the way he actually worked. He did not amass facts in a blind way (this would have been the simplistic perception of Bacon's method in the 19th Century). Rather, he came closer to the original intent of Bacon's (and Kant's) method than just about anyone else in science. Darwin was an interrogationist *par excellence*, in just about all senses of the term. He organized his work along hierarchically nested series of questions; his early entry into the world of science proceeded along the interrogative lines, he was constantly addressing questions to members of

¹⁵ Cf. WALLACE, A. R., *My Life*, Volume I, Dodd, Mead and Company, New York, 1905, pp. 361-363.

¹⁶ Cf. THAGARD, P., *Conceptual Revolutions*, *passim*.

¹⁷ DARWIN, CH., *More Letters of Charles Darwin: A Record of His Work in a Series of Hitherto Unpublished Letters*, 2 vols. Edited by Francis Darwin and A. C. Seward, Appleton and Company, New York, 1903.

the scientific community; and although he was an explorer more than exposé of knowledge, he frequently phrased his arguments in traditional question-answer terms.

The most important one of Darwin's interrogative agenda was the "mystery of mysteries" presented by John Herschel in his letter in 1836 to the geologist Charles Lyell. Darwin refers to the Big Question in his notes¹⁸ and in the opening passage of the *Origin*: "WHEN on Board H. M. S. 'Beagle,' as naturalist, I was much struck with certain facts in the distribution of the organic beings inhabiting South America, and in the geological relations of the present to the past inhabitants of that continent. These facts, as will be seen in the latter chapters of this volume, seemed to throw some light on the origin of species — that mystery of mysteries, as it has been called by one of our greatest philosophers. On my return home, it occurred to me, in 1837, that something might perhaps be made out on this question by patiently accumulating and reflecting on all sorts of facts which could possibly have any bearing on it."¹⁹

These big questions were developed into more manageable subquestions and subsubquestions. In this masterplan the mystery of mysteries, "How is that extinct species have been replaced by others?" is approached via subquestions concerning the nature and extent of variation, generation and inheritance, and along the subsubquestions of variation, generation and heredity on domestic and wild animals, and ditto for flora. Howard Gruber has described the execution of this masterplan as goal-directed activity in which the agenda consists of three subsystems, of organization of knowledge, of purpose, and of affect. Scientific thinking is a series of structural transformations, at all stages of inquiry. Not just the facts but also Darwin's theoretical agenda expanded as a result of such transformations. Starting with the initial notions of natural theology and catastrophism, but facing the facts, he ended up embracing the uniformitarian view that nature is subject to gradual transformations. In Gruber's account questions arise from such transformations as well as from perceived similarities and analogies. The new theoretical horizon, together with the flow of facts, answered some questions but created new ones: "If organisms are perfectly adapted to the milieu for which they were created, what becomes of this adaptation when the milieu changes?" Such questions create disturbances and disturbances create new questions.²⁰

However, Baconian (and Whewellian) scruples prevented him from rushing to the conclusion without adequate empirical backing. So, before making the sweeping selectionist claim public he needed information about the extent of variation, and about the possibilities of selection in domestic and natural populations. The uncertainty was not so much about the existence of variation and selective forces, but about their strength and manner of operation. The way Darwin set out to hunt for facts was through strategically organized series of questions. His notes and manuscripts are littered with questions from issues of metaphysics (for Darwin this was philosophy of mind rather than metaphysics in our sense) to nitty-gritty details concerning, say,

¹⁸ Cf. DARWIN, CH., "Notebook E," in DARWIN, CH., 1987, *Charles Darwin's Notebooks, 1836-1844*, transcribed and edited by P. H., Barrett, P. J., Gautrey, S., Herbert, D., Kohn, and S., Smith, Cambridge University Press, Cambridge, 1987, p. 59.

¹⁹ DARWIN, CH., *On the Origin of Species by Means of Natural Selection or the Preservation of Favoured Races in the Struggle for Life*, John Murray, London, 1859. Facsimile of the 1st edit., Harvard University Press, Cambridge, MA, 1964.

²⁰ GRUBER, H., "The Evolving Systems Approach to Creative Scientific Work: Charles Darwin's Early Thought," in NICKLES, TH. (ed.), *Scientific Discovery: Case Studies*, Reidel, Dordrecht, 1980, pp. 113-130.

pollination by species of insects, or the habits of varieties of bees. Sometimes, when reviewing his notes, Darwin highlighted an important point in pencil with a capital encircled Q.

Darwin also explicitly equated questions with experiments, in his unpublished notes there is a set of questions with the title “Questions” crossed over and the word “Experiments” written in its place. Once he had become convinced *that* transmutation and hence common descent was possible and a likely explanation of the many classes of facts from systematics to paleontology, he was ready to tackle the how and why, that is, the search for an explanatory theory of transmutation. As he says above artificial and later natural, selection emerged as candidates for this role, sometime in 1936-37.

Methodwise, there are two remarkable further features of his work worth noting. First, Darwin had no scruples about relying on the testimony of others, *if* the informant was reliable. In the autobiographical note where he claimed to have worked along Baconian principles he said he collected facts “on a wholesale scale ... *by printed enquiries, by conversation with skilful breeders and gardeners, and by extensive reading.*” (Emphasis added). Where Bacon had dreamed of armies of fact gatherers and interrogators, Darwin made this happen by establishing *ad hoc* workshops at Downe house and by resorting to the world-wide community of amateur and professional naturalists — to provide specimens and scientific information. Again, in the words of Silvain Schweber, this was the pattern for Darwin followed all his life. The key to his success was “not only the skill with which he organized and carried out the in-house anatomical dissections, but also the impressive managerial talents he exhibited in creating the scientific network which made these activities possible.”²¹

During his lifetime Darwin had a host of colleagues, friends and acquaintances who provided needed information, and his correspondence is full of these letters. But the remarkable thing was that he engaged not just his network of fellow naturalists but also animal breeders, missionaries, country doctors, and acquaintances in consulates outside Britain. The very idea of the theory of natural selection builds on the parallel between man’s intentional artificial selection and Nature’s blind but much more effective natural selection. But who else but those who had been involved in artificial selection would have known the extent and limits of variation? Darwin understood better than anyone else that the communities of poultry and livestock breeders, pigeon and rabbit raisers, practical horticulturalists and gardeners all had practiced artificial selection for ages. To make the most of this insight he joined breeders’ clubs, established personal connections with pigeon raisers, and often send requests for varieties he needed for his purposes. These men of practice also had a number of advantages over his usual circles of fellow naturalists or academics. As Secord notes, domesticated animals and cultured plants provided a new realm of facts, facts which would not be available through established channels.²² And secondly, related to this, these facts were organized differently, with an eye on potential practical utility and economic gain to be obtained from useful varieties. The outcome of all this was that Darwin managed to establish an unprecedented network of informants and collaborators whom he sent personal written questions, or engaged in informal discussions, or published “lists of interrogatories.”

²¹ SCHWEBER, S., “The Wider British Context in Darwin’s Theorizing,” in KOHN, D. (ed.), *The Darwinian Heritage*, Princeton University Press, Princeton, NJ, 1985, p. 59.

²² Cf. SECORD, J., “Darwin and the Breeders: A Social History,” in KOHN, D. (ed.), *The Darwinian Heritage*, pp. 519-542.

6. THE DARWINIAN REVOLUTION: THERE IS MORE TO QUESTION THAN MEETS THE EAR

We just saw that the Darwinian Revolution changed radically the way species are identified. But there was more to the revolution, for it changed the entire interrogative agenda. There are in fact several related changes in fundamental concepts that took place at the same time. I shall pick out two for closer scrutiny in this section, viz. the rise of population thinking and the change in our concept of causation. In his book entitled *One Long Argument* Ernst Mayr talks about two Darwinian revolutions.²³ The first revolution was predominantly cognitive or scientific, and complete during Darwin's life-time. It united several so-far disparate fields of naturalist study under the bold proposition that all life forms descend from common origins. The second revolution, in the guise of the synthetic theory, took almost a hundred years to finish, but it too brought about cognitive and professional unification: genetics and traditional naturalist fields came to be viewed from the same evolutionary perspective, with natural selection as the reigning component.

Mayr in fact holds that the first revolution was in the form of two main theories, those of common descent and natural selection that explained common descent, as well as three supplementary theories, namely the theory of "evolution as such" which says that all organisms are subject to a steady process of change; the theory of the multiplication of species which has it that new species may arise through splitting or budding (in geographic isolation, mostly); and gradualism according to which evolution is piecemeal rather than saltational.

I shall not pause over the details of the theory (or controversies surrounding what Darwin really meant) but rather point out to the types of conceptual changes needed and the types of questions that were opened by these revolutions. For the first revolution to take place there had to be a number of conceptual shifts in explanatory ideals and in the ontology that were not mere additions of new beliefs in the existing edifice of knowledge but required giving up deep commitments. As a result, old questions faded out and new types of questions came to the fore. It also turned out that there was talking past one another: a question before the revolution, say about the explanation of a behavioural pattern, was turned into a different question. Salient changes included giving up (Aristotelian) essentialism, the view that species membership was a matter of sharing a defining or essential feature characteristic of that species (this shift is related to the change in the concept of species already noted, that species are identified in terms of genealogy rather than similarity); embracing population thinking, i.e., shifting the focus from individuals to populations; a new way of seeing how causation could work; and giving up the view that organisms were perfectly adapted to their environments. This commitment, the principle of perfect adaptation, required that form and function, or organism and its environment, had to be in perfect harmony (or in a weaker form, that the harmony had to be as close as the laws of nature allowed.)²⁴ So, when explaining why an organism had such-and-such a well-designed organ it was sufficiently explanatory to point that it was designed to perform a function in this best of possible worlds. Darwin had to overcome this conceptual hurdle — the last one before making his views public. It was a particularly difficult one since it was deeply entrenched in the natural philosophy of the time as well as sanctioned by theology: after all, it was part of God's plan.

²³ MAYR, E., *One Long Argument*, The Penguin Press, Allen Lane, 1991.

²⁴ Cf. OSPOVAT, D., *The Development of Darwin's Theory. Natural History, Natural Theology and Natural Selection*, Cambridge University Press, Cambridge, 1981, pp. 26-33.

But let us look at population thinking more closely. Before Darwin evolution was thought to result from changes in the phenotypic properties of individual organisms as well as in the passing of these changes to offspring. Evolutionary changes (the lengthening of the necks of the giraffes etc.) were conceived as consequences of acquired characteristics of individuals. Darwin altered the focus to the population level by suggesting that phenotypic changes as such are not inherited: change in a population is a consequence of heritable variation and selective retention. Exactly what caused variation was largely a mystery and subject to long debate (and continues to be discussed today), but this did not change the way causation worked. Evolution through natural selection in fact requires that acquired traits are not passed on to offspring.

In interrogative terms this means that the question “why do giraffes have long necks” is not a developmental question about how individual organisms change during lifetime but about populations. Mayr in fact generalized this observation about types of question by distinguishing between two kinds of biology and “two kinds of causation.” On one hand there are what he calls proximate causes that “relate to the functions of an organism and its parts as well as its development,” on different levels from functional morphology to biochemistry. On the other hand there are evolutionary or ultimate causes that explain why an organism is the way it is. The two kinds of causation focus on completely different aspects of the natural world, since about the workings of an organ or organism or other biological entity here and now, the other one about the historical emergence of a trait or life-form.

The result is that there is more to a question than meets the ear. When a functional biologist asks “why do New England warblers migrate south” they focus on the intrinsic or extrinsic physiological causes that make these birds head south. Warblers like all migratory birds in general are subject to a phenomenon known as photoperiodicity. They react to decrease in day daylight hours go below a certain level they start their migration. Apart from such intrinsic physiological causes there are also extrinsic ones referring, e.g. a drop in temperature and to other changes in weather etc. So, once already in particular physiological state conditions singled out as readiness for migration an extrinsic cause might explain why migration started on a particular day.

The very same question “why do New England warblers migrate south,” in the mouth of an evolutionist, would mean a different question altogether: she or he focuses on the emergence of the pattern in terms of ultimate causes. These might include mentioning an ecological cause such as the fact that warblers are insect eaters and would not be likely to survive New England winter. Or they might mention a genetic cause that would explain why warblers but not some other species of birds respond to changes of environment in this way.

Mayr’s classification into proximate and ultimate questions easily gets mixed with the somewhat related contrast between proximate and distal, or historical-evolutionary and structural-morphological. I shall not pause over these issues here but confine to pointing out to the importance of Mayr’s contribution.²⁵ Mayr highlights the fact that conceptual change here pertains to the very questions that can be raised. In fact, the community of natural historians and scientists continued to talk past each other long Darwin without realizing that the more precise questions they had, the explananda in modern terms, were different.

Interestingly, although Mayr is on record for pointing out that Darwin brought about a revolution in the life sciences by giving up essentialism and by making populations the focus

²⁵ See BEATTY, J., “The Proximate/Ultimate Distinction in the Multiple Careers of Ernst Mayr,” *Biology and Philosophy*, v. 9, (1994), pp. 333-356; and ARIEW, A., “The Probabilistic Character of Evolutionary Explanations,” *Biology and Philosophy*, v. 13, (1998), pp. 245-253.

of study he nevertheless shares an ideal that goes all the way to Aristotle. Aristotle maintained that the complete understanding of the behaviour of an entity required specification of all four types of causes, formal, material, efficient and final. I like fashion, Mayr maintains that “for a complete understanding of the given phenomenon” we need to understand both the proximate and the ultimate causes.²⁶

7. 21ST CENTURY — NEW REVOLUTIONS IN OFFING?

Quite a few thinkers have expressed the opinion that the 19th Century was the century of physics, whereas the 20th Century was that of biology and the life sciences. That might be so — but the spectacular progress of the life-sciences and medicine have continued to the 21st Century. There are new developments that will no doubt bring about conceptual upheavals almost equal to the Darwinian Revolution, upheavals that could have a fundamental impact on our picture of man and man’s place in the world. One candidate is systems biology which challenges the extant view that biological organisms can be understood as highly complicated and nested mechanisms of mechanisms and that, consequently, can be understood in accordance with the reductionist paradigm that reigns in medicine and the life sciences.²⁷

Another candidate has to do with ontology. We saw that one part of the Darwinian revolution was the introduction of population thinking and the new way of seeing how causation works in natural selection. Yet, although Darwin acknowledge that natural selection could work both on the level of individuals and groups the idea persisted that individual organisms somehow are the fundamental ontological category of biology. There are reasons to think that this picture should be revised, if not jettisoned altogether. As Maureen O’Malley and John Dupré forcibly argue, our biological (and no doubt biomedical) thinking has been shaped by a particular view of life, viz., that organisms are self-contained and static individuals. There are several reasons for this. One is the understandable (but anthropocentric) bias for taking multi-celled organisms, especially those belonging to the kingdoms of animals (Animalia) and plants (Plantae) as paradigms of the living. Yet, both from the point of view of history of life and current diversity of organisms, micro-organisms are far more important. Microbes, such as bacteria and archaea outnumber individual organisms in number and biomass. Macrobes, as O’Malley and Dupré baptize multi-celled macro-organisms, only came into existence much later.²⁸

From the point of view of the life sciences his has important consequences. One is that e.g. a human body contains about 10 times more microbial cells than human somatic and germ cells.²⁹ We could not survive or flourish without the micro-organisms that take care of our metabolism. In fact all macro-organisms are best viewed as superorganisms that consist of a gamut of human cells living in symbiosis with prokaryotes and viruses — that is, microbes. We tend to think of microbes as aliens or even enemies to our somatic bodies but the fact is that our fates are closely intertwined.

²⁶ Cf. MAYR, E., “Cause and Effect in Biology,” *Science*, v. 131, (1961), pp. 1501-1503.

²⁷ See e.g. BOOGERD, F. C., BRUGGEMAN, F. J., HOFMEYER, J.-H. and WESTERFORR, H. V., *Systems Biology. Philosophical Foundations*, Elsevier, Amsterdam, 2007.

²⁸ Cf. O’MALLEY, M. and DUPRÉ, J., “Size Doesn’t Matter: Towards a More Inclusive Philosophy of Biology,” *Biology and Philosophy*, v. 22, (2007), pp. 155-191.

²⁹ Cf. O’MALLEY, M. and DUPRÉ, J., “Size Doesn’t Matter: Towards a More Inclusive Philosophy of Biology,” p. 157.

There is no doubt that viewing ourselves as superorganisms will harbour important conceptual changes — both for the scientific image and the manifest image within which we have come to form our identity. As O'Malley and Dupré note, the history of micro-organisms started with the development of instruments such as the microscope and subsequent experimental work on spontaneous generation. But the ontology of micro-organisms was based on the idea that these entities are static single-celled individuals. In medicine this meant that micro-organisms such as *Staphylococcus aureus* causally responsible for many cases of childbed fever could be isolated, removed from the parent organism and cultivated in laboratory conditions. But his picture of microbes entirely bypasses the fact that they characteristically lead an active “social” life with members of the same species and that they live in symbiosis with members of other species.

We do not know, yet, how these developments affect medicine and the life sciences in detail. But they do point to some interesting revolutionary vistas: for instance systems biology and synthetic biology will enable personalised medicine — medical treatment and promotion of health based on detailed knowledge of an individual's (or groups) genome. This also means that new realms of questions, practically and theoretically motivated, will arise also in the future.

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CONCEPTUAL CHANGE IN MEDICINE: EXPLAINING MENTAL ILLNESS

Paul Thagard and Scott Findlay

1. INTRODUCTION

Many people are afflicted by mental illnesses such as depression and schizophrenia, but there has been much controversy about the nature and origin of such disorders. Are they the result of demonic possession, bodily imbalances, faulty childhoods, social control, genetic defects, nutritional inadequacies, or other factors? Are mental illnesses biological disorders like cancer and influenza, or are they mere social constructions? In the more than two millennia that people have thought about mental illnesses, there have been many changes in the conceptualization of psychological disease in general and of particular mental problems such as epilepsy. This paper will describe the nature of these conceptual changes and provide a discussion of the current evolving state of deliberations about mental illness.

First we will provide a quick review of how explanations of classifications of mental illnesses have changed dramatically over the centuries. This review will show that the history of understanding of medical illnesses displays the radical kinds of conceptual change that have occurred in the history of science, including not only reclassification of diseases but also fundamental changes in the way that classification has been performed. Then we will argue that classification, diagnosis, and treatment of mental illnesses needs to be based on multilevel explanations that take into causal mechanisms that operate on at least four different levels: social, psychological, neural, and molecular. We will illustrate the complex causality of mental illnesses by describing very recent research on epigenetics, which concerns the molecular control of gene activity by environmental factors.

2. CONCEPTUAL CHANGE

In *Conceptual Revolutions*, Thagard provided a comprehensive account of kinds of conceptual change in major scientific revolutions, from Copernicus to Darwin to Einstein.¹ Some conceptual change involves only minor modifications to existing concepts, as scientific research shows that a disorder such as schizophrenia can be treated by a newly developed drug. But more important modifications to concepts include the following:

- Introduction of new concepts such as *schizophrenia*.
- Abandonment of old ones such as *demonic possession*.

¹ Cf. THAGARD, P., *Conceptual Revolutions*, Princeton University Press, Princeton, 1992.

- Differentiation of concepts into subtypes such as *depression* to include *manic depression*.
- Reclassification of concepts from one category to another, for example identifying epilepsy as a kind of bodily disorder instead of as a kind of divine visitation.
- Changing the ways in which classifications are done, for example using underlying physical causes rather than observable symptoms.

We can find instances of all these kinds of conceptual changes in the history of thinking about mental illness.

Historians have identified many important developments in the description and explanation of mental illness.² The first important shift took place in Greece in the fifth century B. C., when Hippocrates argued against the prevailing view of that epilepsy was a “sacred disease” caused by visitations from the gods. Instead, in keeping with his general theory that diseases are caused by imbalances in the four humors (phlegm, blood, yellow bile, black bile), Hippocrates argued that madness results from problems with the brain:

Men ought to know that from nothing else but the brain come joys, delights, laughter and sports, and sorrows, griefs, despondency, and lamentations. And by this, in an especial manner, we acquire wisdom and knowledge, and see and hear, and know what are foul and what are fair, what are bad and what are good, what are sweet, and what unsavory; some we discriminate by habit, and some we perceive by their utility. By this we distinguish objects of relish and disrelish, according to the seasons; and the same things do not always please us. And by the same organ we become mad and delirious, and fears and terrors assail us, some by night, and some by day, and dreams and untimely wanderings, and cares that are not suitable, and ignorance of present circumstances, desuetude, and unskilfulness. All these things we endure from the brain, when it is not healthy, but is more hot, more cold, more moist, or more dry than natural, or when it suffers any other preternatural and unusual affection. And we become mad from its humidity. For when it is more moist than natural, it is necessarily put into motion, and the affection being moved, neither the sight nor hearing can be at rest, and the tongue speaks in accordance with the sight and hearing.³

The humoral theory of disease dominated European medicine for thousands of years until Pasteur’s germ theory came along in the mid-nineteenth century. Mental illnesses such as epilepsy may not have anything to do with the moisture level of the brain, but Hippocrates made a great advance in recognizing them as problems of the brain rather than as the result of heavenly interventions, as the Assyrians, Egyptians, and earlier Greeks had assumed. Hence Hippocratic theories introduced a dramatic reclassification of mental illnesses as biological disorders rather than supernatural afflictions.

That reclassification was far from universally accepted, and theological and mystical explanations of mental illnesses survive even today. More sophisticated biological explanations were slow in coming, with few developments until the seventeenth century when physicians

² E.g., PORTER, R., *Madness: A Brief History*, Oxford University Press, Oxford, 2002; and SHORTER, E., *A History of Psychiatry*, John Wiley and Sons, New York, 1997.

³ Cf. HIPPOCRATES, *On the Sacred Disease*, 400 B.C. Available from <http://classics.mit.edu/Hippocrates/sacred.html> (access on January 12, 2010).

such as Thomas Willis, Archibald Pitcairn, and Herman Boerhave began to develop mechanistic ideas based on organs, nerves, fibres, and fluids that could be applied to madness. In the eighteenth century explanations of mental functioning took a psychological turn through the writings of philosophers such as Locke and Condillac. During the nineteenth century, psychiatry developed as a branch of medicine in both France and Germany, with the French emphasizing psychological descriptions and explanations, and the Germans emphasizing the neurological. These developments generated a tension that survives today, between biological and psychological explanations of mental functioning. The next section will suggest a way of overcoming this tension by considering multilevel mechanisms.

The twentieth-century rise of Freudian psychoanalysis shifted psychiatry toward concern with psychological explanations. Although Freud began with a strong interest in neural mechanisms, he quickly moved on to psychological matters such as the workings of the unconscious and the lingering effects of childhood sexuality. In the second half of the twentieth century, psychiatry shifted back in more biological directions. The major impetus in this direction came from the discovery of antipsychotic medicines in the 1950s that provided effective ways of reducing the symptoms of schizophrenia. Other important discoveries were the use of lithium for treating manic depression (also known as bipolar disorder) and the development of drugs for anxiety and depression. Initially, these drugs were used without much understanding of why they worked, but developments in molecular biology and neuroscience generated increasingly deep understanding of the underlying mechanisms by which drugs relieved the symptoms of many important mental illnesses through effects on such key neurotransmitters as dopamine and serotonin.⁴ Dramatic developments in genetics also contributed to understanding of the biological bases of mental illnesses, which epidemiological evidence showed to have strong (but not exclusively) inherited components.

It should be evident from our quick sketch of the conceptual developments in psychiatry that this history cannot be viewed as a simple accumulative process in which better ideas replace their inferior predecessors. The alternating swings between psychological and neurological views of mental illness involve non-cumulative conceptual shifts, from thinking of mental illnesses as disorders with psychological causes to thinking of them as neurological, and back again. The crucial question is what kinds of condition mental illnesses are, with very different general and particular concepts arising from considering them in either psychological or neural terms.

In the 1960s, a much more radical reclassification was suggested by the “anti-psychiatry” movement that denied the objectivity of both psychological and neurological accounts of mental illness. Writers such as Thomas Szasz, R. D. Laing, and Michel Foucault contended that mental illnesses are not objective disorders but rather social categories used for control of unruly people.⁵ If this view had become dominant — and it still has supporters in some postmodernist

⁴ Cf. MEYER, J. S. and QUENZER, L. F., *Psychopharmacology: Drugs, the Brain and the Behavior*, Sinauer, Sunderland, MA, 2005; and THAGARD, P., “Conceptual Change in Cognitive Science: The Brain Revolution,” in GONZALEZ, W. J. (ed.), *Conceptual Revolutions: From Cognitive Science to Medicine*, Netbiblo, A Coruña, 2011, pp. 65-78.

⁵ See SZASZ, TH. S., *The Myth of Mental Illness: Foundations of a Theory of Personal Conduct*, Harper and Row, New York, 1961; LAING, R. D., *The Politics of Experience*, Pantheon, New York, 1967; and FOUCAULT, M., *Madness and Civilization: A History of Insanity in the Age of Reason*, Pantheon, New York, 1965.

circles — then mental illnesses ought to be reclassified as bogus social constructions. For reasons to resist such reclassification, see for example Thagard.⁶

Within mainstream psychiatry, mammoth conceptual development took place through the issuing of successive editions of the American Psychiatric Association's *Diagnostic and Statistical Manual (DSM)* in 1952, 1968, 1980, 1994, and 2000. The most striking change is the proliferation of disorders: the most recent version, DSM-IV-TR has more than 900 pages and several hundred disorders. Not only have new concepts applying to distinct mental disorders been introduced, but some concepts were dropped in subsequent editions. For example, homosexuality was classed as a disorder in the first two editions, but not in the third and later ones. For historical and philosophical discussions of the DSM, see Kutchins and Kirk and Murphy.⁷ DSM-V is now under construction with an attempt to make the resulting classifications more consistent with the increasing number of neurological findings about mental illness deriving from brain scanning and other technological developments.

This survey of the history of psychiatry has been very brief, but it provides evidence for the claim made at the beginning of this section that investigations of mental illnesses have introduced major conceptual changes. Attempts to explain and treat mental illnesses have led to classifications that at sometimes introduce new concepts, abandon old ones, and shift mental illnesses among categories. Controversies still reign about how whether mental illnesses should be classified psychologically based on behaviors, neurologically based on underlying biological conditions, or sociologically based on social determinants. The next section will attempt to reconcile some of these competing viewpoints.

3. MULTILEVEL EXPLANATIONS IN MEDICINE

Dictionaries often define an illness or disease as an impairment of normal physiological function. We want to propose a much broader conception of disease as a serious malfunctioning in a system of multilevel interacting mechanisms. This approach draws on recent work on mechanistic explanation in psychology, neuroscience, and other fields.⁸

Modifying Bunge,⁹ we can define a system as a quadruple, <Environment, Parts, Interconnections, and Changes>, EPIC for short. The parts are the objects (entities) that compose the system. To take a biological example, a body is composed of such parts as the head, torso, arms, and legs. The environment is the collection of items that act on the parts, which for a body would include other people and things that interact with it. The interconnections are the relations among the parts, especially the bonds that tie them together. In a body, key relations

⁶ Cf. THAGARD, P., "Mental Illness from the Perspective of Theoretical Neuroscience," *Perspectives in Biology and Medicine*, v. 51, (2008), pp. 335-352.

⁷ Cf. KUTCHINS, H. and KIRK, S., *Making Us Crazy*, Free Press, New York, 1997; and MURPHY, D., *Psychiatry in the Scientific Image*, The MIT Press, Cambridge, MA, 2006.

⁸ See THAGARD, P., *Hot Thought: Mechanisms and Applications of Emotional Cognition*, The MIT Press, Cambridge, MA, 2006; THAGARD, P., "Who Are You? The Self as a System of Multilevel Interacting Mechanisms," *unpublished manuscript - University of Waterloo*, forthcoming; BUNGE, M., *Emergence and Convergence: Qualitative Novelty and the Unity of Knowledge*, University of Toronto Press, Toronto, 2003; and BECHTEL, W., *Mental Mechanisms: Philosophical Perspectives on Cognitive Neuroscience*, Routledge, New York, 2008.

⁹ Cf. BUNGE, M., *Emergence and Convergence: Qualitative Novelty and the Unity of Knowledge, passim*.

include the physical connections between head, neck, torso, and limbs. Finally, the changes are the processes that make the system behave as it does.

A person cannot be easily decomposed into a single EPIC system. Even an organ can be understood at multiple physical levels, for example with the human heart decomposing into various parts such as the chambers and valves, each of which consist of molecules, which consist of atoms, which consist of sub-atomic particles, which may consist of quarks or multidimensional strings. To characterize multilevel systems, we can generalize the EPIC idea and think of a multilevel system as consisting of a series of quadruples, with the structure:

$$\begin{aligned} &\langle E_1, P_1, I_1, C_1 \rangle \\ &\langle E_2, P_2, I_2, C_2 \rangle \\ &\dots \\ &\langle E_n, P_n, I_n, C_n \rangle \end{aligned}$$

At each level, there is a subsystem consisting of the relevant environment, parts, interconnections, and changes. See Thagard for further analysis and an extended argument that the human self should be understood as a system of interacting mechanisms operating at four levels: social, psychological, neural, and molecular.¹⁰ Now we will try to show the implications of this interpretation for understanding mental illness.

To provide a concrete example, consider the discussion of suicide by Goodwin and Jamison in their standard text on manic-depressive illness.¹¹ They report that suicide is far more common among people with this illness than among the general population, and say that “it is clear that suicide is caused by a potent combination of biological and psychosocial risk factors.”¹² Their discussion includes the following factors:

- Genetic and family transmission: Partial heritability of suicidal behavior is shown by studies of families, twins, and adoptees.
- Neurobiological factors: There are associations of suicide with serotonin hypofunction, alterations in norepinephrine function, and hyperactivity in the hypothalamic-pituitary-adrenal axis.
- Psychological traits and temperament: A passive sense of hopelessness is a chronic risk factor for suicide.
- Social factors: Stressors such as job losses, relationship breakups, and legal proceedings can precipitate suicide.

These factors suggest that understanding manic-depressive illness will require attention to mechanisms at four levels: the molecular, neural, psychological, and social. Each of these can be characterized in EPIC terms with respect to Environment, Parts, Interconnections, and Changes.

¹⁰ Cf. THAGARD, P., “Conceptual Change in Cognitive Science: The Brain Revolution,” in GONZALEZ, W. J. (ed.), *Conceptual Revolutions: From Cognitive Science to Medicine*, pp. 65-78; and THAGARD, P., “Who Are You? The Self as a System of Multilevel Interacting Mechanisms,” *unpublished manuscript - University of Waterloo*, forthcoming.

¹¹ Cf. GOODWIN, F. K. and JAMISON, K. R., *Manic-Depressive Illness: Bipolar Disorders and Recurrent Depression*, 2nd ed., Oxford University Press, Oxford, 2007.

¹² GOODWIN, F. K. and JAMISON, K. R., *Manic-Depressive Illness*, p. 255.

The relevance of the molecular level is most clearly shown by the partial genetic heritability of bipolar illness and the success of the most common treatment for the disorder, administration of lithium, which affects levels of dopamine, serotonin, and other neurotransmitters. The functioning of these neurotransmitters only makes sense in the context of the interactive firing activities of billions of neurons, so the neural level is clearly relevant also. Thus at the molecular and neural levels we have interactions between two kinds of parts: chemicals such as dopamine at the molecular level, and cells such as neurons and astrocytes at the neural level.

At the psychological level, the relevant parts are less clear, but it is common in cognitive science to think of mental processes as resulting from the computational interactions of various kinds of mental representations, which can include concepts, rules, images, and analogies.¹³ It is unusual to think of the mind as having mental representations as parts, but the explanatory successes of contemporary psychological theory justify this shift away from commonsense ways of talking about the mind. At the social level, the parts are obviously people whose interactions can have strong effects on the thoughts and behaviors of people in general, not just of bipolar patients who are spurred to suicide by negative events in their jobs, romances, or legal situations.

We are now in a position to offer a broad view of the nature and causation of mental illness. For a relatively simple illness such as Huntington's disease, causality can be characterized at one level, the molecular, because the disease originates from a mutation in a specific gene that produces a specific protein crucial for brain functioning. But proper mental functioning more generally requires good performance of at all levels, including the neural, psychological, and social, as previously discussed. Correlatively, mental illnesses such as depression involve malfunctioning at multiple levels, from the molecular (inadequate serotonin levels) to the neural (patterns of neural firing) to the psychological (obsessive negative thoughts) to the social (bad relationships that can be both causes and effects of depression). Hence mental illnesses involve breakdowns in mechanisms at multiple levels, eliminating the need to settle the ancient controversies over whether the causes of madness are psychological, biological, or social. All of these levels are relevant to explaining both successful functioning of human beings, and also the serious kinds of malfunctioning found in mental illness.

The case for multilevel explanations of mental illness can also be made by reference to other diseases. Schizophrenia, for example, clearly has molecular causes, as shown by the high level of heritability found through twin studies and the efficacy of dopamine antagonists in its treatment. On the other, social and psychological causation also is evident from the fact that schizophrenia is strikingly more common in children of immigrants.¹⁴ Similarly, multilevel causality of depression is shown by the evidence that the most successful treatments tend to be combined ones that operate both at the molecular/neural levels via anti-depressant medications and at the social/psychological levels via psychotherapy. Multilevel causality should not be surprising,

¹³ See SMITH, E. E. and KOSSLYN, S. M., *Cognitive Psychology: Mind and Brain*, Pearson Prentice Hall, Upper Saddle River, NJ, 2007; and THAGARD, P., *Mind: Introduction to Cognitive Science*, 2nd ed., The MIT Press, Cambridge, MA, 2005.

¹⁴ See BENTALL, R., *Madness Explained: Psychosis and Human Nature*, Penguin, London, 2004; and COOPER, B., "Immigration and Schizophrenia: The Social Causation Hypothesis Revisited," *British Journal of Psychiatry*, v. 86, (2005), pp. 361-363.

since it is also found in non-mental illnesses such as cancer and heart disease, which result from factors ranging from the molecular — genetic mutation, high cholesterol — to the social — second hand smoking, job stress.¹⁵

To illustrate the growing importance of multilevel explanations of mental illness, we will review an important recent development in medical science, the rapidly growing field of epigenetics.

4. EPIGENETICS

4.1. *Scientific Explanations in Epigenetics*

Many diseases have been linked to genetic malfunctions, and some such as cystic fibrosis and Huntington's are the result of specific kinds of mutations. However, the operations of genes are turning out to be far more complicated than previously suspected, leading to a new class of epigenetic diseases. Epigenetic explanations are important since they provide a mechanistic account of how environmental and genetic factors can interact in biological processes such as development and the onset of disease. We will describe how epigenetics provides a new kind of disease explanation schema and hence produces a change in the concept of disease, including mental illness.

Epigenetics refers to that which is applied "*upon* the genes." The term was first included in scientific explanations concerning developmental biology by Conrad H. Waddington in 1942.¹⁶ Today, epigenetics usually refers to changes in the genetic material that affect gene expression independent of any differences in the DNA sequence itself. Central to the concepts of epigenetics are mechanistic explanations of how various modifications made to the genetic material can affect gene expression. Today, the emerging field of epigenetics is introducing a new level of explanation into the explanatory framework used by scientists to explain phenomenon ranging from early embryonic development to the etiology of widespread mental illnesses.

The simplest illustration of the importance of epigenetics presents itself when considering mammalian development. Different adult cell types that make up various tissues appear wildly different to us, and they are. However, skin cells, liver cells, and every other cell in our own bodies were all derived from a small collection of genetically identical embryonic stem cells. How can two genetically identical cells give rise to two completely different adult cells? How does a liver cell know to divide to give rise to new liver cells and not skin cells after thousands of divisions? Answers to these questions are provided by epigenetics. Since the entire genome is replicated for each cell division, the information necessary to specify cell type cannot be contained within the DNA sequence itself. Instead, different transient environmental signals during early development turn on some genes and silence others, thus modifying gene expression to achieve the appropriate adult cell type. This is accomplished by modifying DNA-containing chromatin, the genetic material, in ways that are both semi-stable and heritable. The two main mechanisms behind these modifications involve the post-translational modification of proteins

¹⁵ Cf. THAGARD, P., *How Scientists Explain Disease*, Princeton University Press, Princeton, 1999.

¹⁶ Cf. RICHARDS, E. J., "Inherited Epigenetic Variation — Revisiting Soft Inheritance," *Nature Reviews Genetics*, v. 7, n. 5, (2006), pp. 395-401.

found within chromatin known as histones, and the methylation of individual units of DNA. We will discuss these mechanisms next, summarizing Levenson.¹⁷

4.2. Epigenetic Modifications and their Mechanisms

Histones are proteins that make up chromatin along with DNA. Both components are closely associated in chromatin, with about 147 base pairs (structural units) of DNA wrapping around a core histone octamer (made of two copies of each of the histone proteins H2a, H2b, H3, and H4) to form what is called a nucleosome.¹⁸ This association is mediated by the attractive force between the negatively charged phosphate groups that line the backbone of DNA, and the positively charged basic amino acid residues that are abundant in histones. The wrapping of DNA around histones provides one level of folding for the genetic material. Additional levels of folding occur for chromatin to be bundled into the chromosomes we can see under the microscope in our actively dividing cells.

Residues on slim “tails” that extend away from each of the core histone proteins can be modified by the addition of small chemical groups to affect the attraction between histones and DNA. Such modifications include acetylation, phosphorylation, methylation, ubiquitination, and sumoylation.

Acetylation of lysine (K) residues by a class of enzymes known as histone acetyl transferases (HAT) is associated with transcriptional activation. The positively charged lysine side chain is neutralized upon addition of an acetyl group. This weakens the interaction between histones and DNA and allows increased access of cellular machinery for transcription (making new RNA based on a DNA template) that will later be used to make protein. A long stretch of transcriptionally active chromatin can be referred to as euchromatin.

Conversely, histone deacetylases (HDAC) can act to remove an acetyl group, promote a stronger interaction between histone and DNA, and reduce or repress transcription. A long stretch of transcriptionally repressed chromatin can be referred to as heterochromatin.

Phosphorylation of serine residues found on histone tails is also associated with transcriptional activation and is catalyzed by protein kinase enzymes and reversed by phosphatase enzymes.

In a similar fashion, histone methyl transferase (HMT) and histone demethylase (HDM) enzymes can catalyze the methylation and demethylation of lysine residues, respectively. However, methylation can be associated with either increased or decreased levels of expression, depending on the residues affected. The “histone code hypothesis” suggests that certain modifications made to certain histone residues are either associated with transcriptional activation or repression, and their combined effects determine the overall accessibility of chromatin for transcription in a given region.

In addition to histone modifications, special substitution of histone octamer components, the sliding of nucleosomes along DNA, and the outright eviction of nucleosomes, all contribute to changes in gene expression. Collectively these mechanisms are referred to as chromatin remodeling.

¹⁷ Cf. LEVENSON, J. M. and SWEATT, J. D., “Epigenetic Mechanisms in Memory Formation,” *Nature Reviews Neuroscience*, v. 6, (2005), pp. 108-118.

¹⁸ Reviewed in TSANKOVA, N. M., RENTHAL, W., KUMAR, A. and NESTLER, E. J., “Epigenetic Regulation in Psychiatric Disorders,” *Nature Reviews Neuroscience*, v. 8, n. 5, (2007), pp. 355-367.

DNA methylation is another common epigenetic modification. In mammals such as humans, methylation involves the covalent addition of a methyl group (CH_3) to the fifth position of cytosine (C) bases found in DNA. A cytosine base “tagged” in this fashion is referred to as 5-methyl cytosine (5mC). Enzymes that carry out this methylation are known as DNA methyl transferases (DNMT). Importantly, these enzymes only recognize a cytosine base as a candidate for methylation when it is found directly before a guanine (G) base. The two bases are only separated by a phosphate group and are commonly represented by “CpG.” Areas where CpG sequences are clustered closely together and are found more frequently than would be expected by chance are called “CpG islands.” These islands are common in the upstream regulatory regions of many genes. Hypermethylation of these regions is usually associated with transcriptional silencing of the downstream gene. Conversely, hypomethylation is usually associated with an active transcriptional state of the downstream gene. Methylated bases are also known to interact with other proteins involved in chromatin remodeling and histone modification, demonstrating an important link between these two epigenetic mechanisms.

4.3. Epigenetic Systems

The two mechanisms discussed above, as well as a third mechanism involving RNA silencing, contribute to several systems of epigenetic regulation in addition to the simple regulation of individual gene expression described above. Two of these epigenetic systems are X-chromosome inactivation and genetic imprinting.¹⁹ The former occurs in XX females since they have double the amount of X chromosome genes as their male (XY) counterparts and therefore achieve “dosage compensation” by silencing one entire X chromosome in every cell. Several RNA molecules play a major role by physically interacting with the X chromosome that is to be silenced.²⁰

Genetic imprinting involves the hemizygous (from only one allele) expression of certain genes in a parent of origin-dependent manner. It is believed that around 100-200 human genes are expressed from the paternal chromosome (inherited from our father) and remain silenced on the corresponding maternal chromosome (inherited from your mother) or vice versa.²¹ Many of the epigenetic mechanisms discussed above are involved in imprinting. It is important to understand that the effect of genetic imprinting is not that paternal and maternal chromosomes have a different sequence of DNA in a given region, but that expression of one parent’s gene is encouraged while expression of the corresponding gene is silenced.

4.4. Epigenetics Can Explain Gene-Environment Interactions

Epigenetic explanations are very powerful since they provide a detailed mechanistic account for how both environmental and genetic factors might interact to affect biological processes such as development, behavior, and the onset of disease. In this framework, the effects of the environment and genetic factors are no longer mutually exclusive. Figure 1 provides a simplified illustration of how the epigenetic state of the entire genome known as the “epigenome” is influenced by genetic, epigenetic, and environmental factors.

¹⁹ See RICHARDS, E. J., “Inherited Epigenetic Variation — Revisiting Soft Inheritance,” pp. 395-401, for discussion of these and others.

²⁰ Reviewed in “Inherited Epigenetic Variation — Revisiting Soft Inheritance,” pp. 395-401.

²¹ Cf. *Catalogue of Parents of Origin Effects. Imprinted Genes and Related Effects. Parental Origins of de novo Mutations*, available in <http://igc.otago.ac.nz/home.html> (access on March 2, 2010).

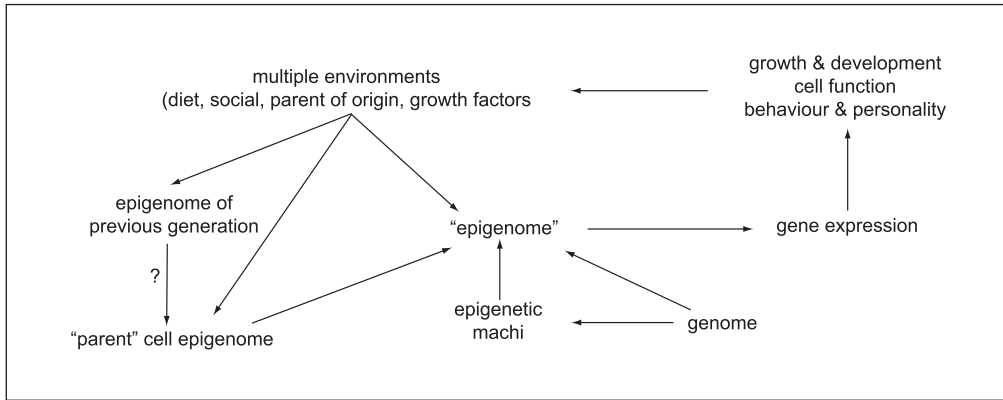


Figure 1. A simplified illustration of the framework of epigenetic explanations of biological phenomena. Solid arrows represent causal relations. The large box indicates a single cell (for example a neuron) of interest. The question mark indicates that the possibility of transgenerational inheritance of epigenetic states in humans is controversial and still largely speculative.

4.5. Metastable Epialleles

The concept of a metastable epiallele is also important in epigenetic explanations. It can be defined as a region of the genome that can account for phenotypic differences between genetically identical cells (and individuals) based on epigenetic modifications that are both variable and reversible.²² The best example of one such gene is the mouse *A^y* (viable yellow agouti) created by the insertion of an intracisternal A particle (IAP) transposable element upstream of the normal agouti (*A*) allele. In this transgenic system, the methylation state of the IAP determines if proper expression of the *agouti* gene takes place. Ectopic expression of the gene occurs when the IAP element is hypomethylated and is marked phenotypically by a yellow coat colour, obesity, and diabetes. Highly methylated IAP induces normal expression of the *agouti* gene and results in a brown coat colour. The degree of IAP methylation can vary in a random fashion, but interestingly can also be influenced by maternal diet during early development of offspring. Maternal diets supplemented with the methyl donor folic acid were shown to result in a higher proportion of brown pups. This effect was indeed mediated by increased methylation of CpG sites in the IAP.²³ Although a transgenic model was used, this is a great illustration of how one small environmental component can have great effects on gene expression as mediated by epigenetic and genetic mechanisms. These types of explanations may prove to be central not only to growth and development, but to the etiology of human conditions as complex as cancer, and mental illnesses such as major depressive disorder (MDD).

²² Cf. JIRTLE, R. L. and SKINNER, M. K., "Environmental Epigenomics and Disease Susceptibility," *Nature Reviews Genetics*, v. 8, n. 4, (2007), pp. 253-262.

²³ Cf. WOLFF, G. L., KODELL, R. L., MOORE, S. R. and COONEY, C. A., "Maternal Epigenetics and Methyl Supplements Affect Agouti Gene Expression in *Avy/a* mice," *The FASEB Journal*, v. 12, n. 11, (1998), pp. 949-957; WATERLAND, R. A. and JIRTLE, R. L., "Transposable Elements: Targets for Early Nutritional Effects on Epigenetic Gene Regulation," *Molecular and Cellular Biology*, v. 23, n. 15, (2003), pp. 5293-5300; and COONEY, C. A., DAVE, A. A. and WOLFF, G. L., "Maternal Methyl Supplements in Mice Affect Epigenetic Variation and DNA Methylation of Offspring," *The Journal of Nutrition*, v. 132, n. 8, sup., (2002), pp. 2393S-2400S.

4.6. Epigenetic Explanations of Disease

Thagard uses a collection of *explanation schemas* to outline the causes of numerous diseases.²⁴ Today, our knowledge calls for the addition of an epigenetic explanation schema to such explanations of disease. Epigenetics might be able to help explain aspects of complex multi-factorial diseases for which good explanations do not always exist. An explanation schema for diseases classified as epigenetic would look something like this:

Explanation target:

Why does a **patient** have a **disease** with associated **symptoms**?

Explanatory pattern:

The **patient** has an **epimutation** affecting the accessibility of **gene(s)** in a given region of **chromatin**.

Improper expression of **gene(s)** produces the **disease** and its **symptoms**.

“Epimutation” is used here to mean “any mistake in the epigenetic modification(s) of a particular region of chromatin.” The concept is based on that of “mutation” which refers to a mistake in the sequence of DNA itself. An epimutation can originate in the affected cell or can be inherited upon division of its “parent cell.” The ultimate cause of an epimutation in either case is either genetic or environmental in nature.

“Environment” is used in a broad sense to account for a wide range of non-genetic factors that might be implicated in the etiology of complex disease. At the molecular level, many such factors have been shown to affect the epigenome. For example, a small region of chromatin might have one pattern of DNA methylation or another depending on if it was inherited maternally or paternally. Exposure to certain chemicals during pregnancy can affect the state of an offspring’s epigenome.²⁵ DNA methylation patterns can change in response to nutritional restriction during gestation in rats.²⁶ Additionally, a maternal diet deficient in folic acid has shown to have a wide variety of teratogenic effects, perhaps due to reduced availability of methyl groups usually stripped from folic acid to ultimately be used for DNA methylation.²⁷ The early social

²⁴ Cf. THAGARD, P., *How Scientists Explain Disease, passim*.

²⁵ Cf. Reviewed in SZYF, M., “The Early Life Environment and the Epigenome,” *Biochimica et Biophysica Acta*, v. 1790, n. 9, (2009), pp. 878-885.

²⁶ See MACLENNAN, N. K., JAMES, S. J., MELNYK, S., PIROOZI, A., JERNIGAN, S., HSU, J. L., JANKE, S. M., PHAM, T. D. and LANE, R. H., “Uteroplacental Insufficiency Alters DNA Methylation, One-Carbon Metabolism, and Histone Acetylation in IUGR Rats,” *Physiological Genomics*, v. 18, n. 1, (2004), pp. 43-50; KE, X., LEI, Q., JAMES, S. J., KELLEHER, S. L., MELNYK, S., JERNIGAN, S., YU, X., WANG, L., CALLAWAY, C. W., GILL, G., CHAN, G. M., ALBERTINE, K. H., MCKNIGHT, R. A. and ANE, R. H., “Uteroplacental Insufficiency Affects Epigenetic Determinants of Chromatin Structure in Brains of Neonatal and Juvenile IUGR Rats,” *Physiological Genomics*, v. 25, n. 1, (2006), pp. 16-28; and SINCLAIR, K. D., ALLEGRUCCI, C., SINGH, R., GARDNER, D. S., SEBASTIAN, S., BISPHAM, J., THURSTON, A., HUNTLEY, J. F., REES, W. D., MALONEY, C. A., LEA, R. G., CRAIGON, J., McEVoy, T. G. and YOUNG, L. E., “DNA Methylation, Insulin Resistance, and Blood Pressure in Offspring Determined by Maternal Periconceptional B Vitamin and Methionine Status,” *Proceedings of the National Academy of Sciences of the USA*, v. 104, n. 49, (2007), pp. 19351-19356, all reviewed in SZYF, M., “The Early Life Environment and the Epigenome,” *passim*.

²⁷ Cf. WAINFAN, E., DZIK, M., STENDER, M. and CHRISTMAN, J. K., “Rapid Appearance of Hypomethylated DNA in Livers of Rats Fed Cancer-Promoting, Methyl-Deficient Diets,” *Cancer Research*, v. 49, n. 15, (1989), pp. 4094-4097; POGRIBNY, I. P., MILLER, B. J. and JAMES, S. J., “Alterations in Hepatic p53 Gene Methylation Patterns during Tumor Progression with Folate/Methyl Deficiency in the Rat,” *Cancer Letters*, v. 115, n. 1, (1997), pp. 31-38; and BRUNAUD, L., ALBERTO, J. M., AYAV, A., GERARD, P., NAMOUR, F., ANTUNES, L., BRAUN, M., BRONOWICKI, J. P., BRESLER, L. and GUEANT, J. L., “Effects of Vitamin B12 and Folate Deficiencies on DNA Methylation and Carcinogenesis in Rat Liver,” *Clinical Chemistry and Laboratory Medicine*, v. 41, n. 8, (2003), pp. 1012-1019, all reviewed in SZYF, M., “The Early Life Environment and the Epigenome,” *passim*.

environment can also affect behaviour in a way that is mediated by epigenetics. For example, attenuated hypothalamic–pituitary–adrenal (HPA) stress response has been associated with high levels of glucocorticoid receptor (GR) mRNA.²⁸ Rat pups raised by mothers who licked and groomed their pups more often showed higher levels of GR mRNA in the hippocampus than those who licked and groomed their pups less. This effect was independent of genetic and prenatal factors.²⁹ Importantly, this increase in GR was associated with decreased HPA stress response as expected.³⁰ This association appears to be mediated by decreased methylation of the GR 1₇ gene promoter in the hippocampus that is established during the first week of life and retained into adulthood.³¹ See Champagne and Curley for a review of stress response studies.³²

Genetic causes of epimutation are usually due to a simple mutation in a gene that normally codes for a component of epigenetic regulation such as a HAT or DNMT. A simplified illustration of the causes of epimutation and how they contribute to complex disease are shown in Figure 2.

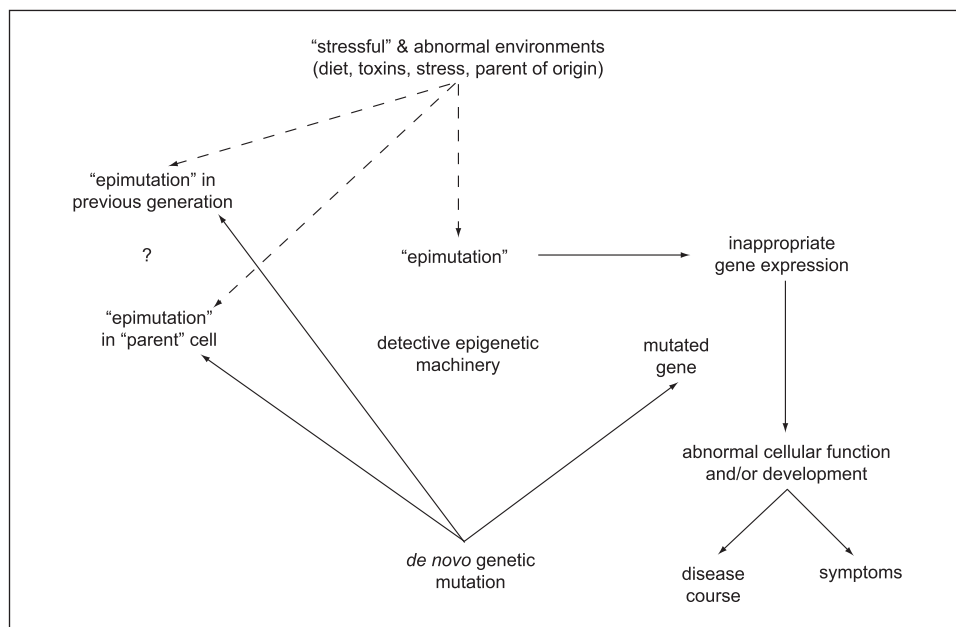


Figure 2. Illustration of a generalized diseased state due to epimutation. Solid arrows indicate causal relations. The large box indicates a single cell (for example a neuron) of interest.

²⁸ Cf. JACOBSON, L. and SAPOLSKY, R., “The Role of the Hippocampus in Feedback Regulation of the Hypothalamic–Pituitary–Adrenocortical Axis,” *Endocrine Reviews*, v. 12, n. 2, (1991), pp. 118–134.

²⁹ Cf. CHAMPAGNE, F. A., FRANCIS, D. D., MAR, A. and MEANEY, M. J., “Variations in Maternal Care in the Rat as a Mediating Influence for the Effects of Environment on Development,” *Physiology and Behavior*, v. 79, n. 3, (2003), pp. 359–371.

³⁰ See CALDJI, C., DIORIO, J. and MEANEY, M. J., “Variations in Maternal Care in Infancy Regulate the Development of Stress Reactivity,” *Biological Psychiatry*, v. 48, n. 12, (2000), pp. 1164–1174.

³¹ Cf. WEAVER, I. C., CERVONI, N., CHAMPAGNE, F. A., D’ALESSIO, A. C., SHARMA, S., SECKL, J. R., DYMOV, S., SZYF, M. and MEANEY, M. J., “Epigenetic Programming by Maternal Behavior,” *Nature Neuroscience*, v. 7, n. 8, (2004), pp. 847–854.

³² Cf. CHAMPAGNE, F. A. and CURLEY, J. P., “Epigenetic Mechanisms Mediating the Long-term Effects of Maternal Care on Development,” *Neuroscience and Biobehavioral Reviews*, v. 33, n. 4, (2009), pp. 593–600.

The question mark indicates that the possibility of transgenerational inheritance of epigenetic states in humans is controversial and still largely speculative.

4.7. Types of Epigenetic Diseases

Like some other diseases, we can think about epigenetic diseases in terms of a hierarchy of schemas (Figure 3) made up of the general epigenetic disease schema, different explanation schemas depending on the type of epigenetic modification or system that is being perturbed in each disease, and lastly, schemas for each individual disease.³³ It is important to note that these categorizations are very simplified, and some diseases arise due to the perturbation of multiple epigenetic mechanisms and other non-epigenetic factors.

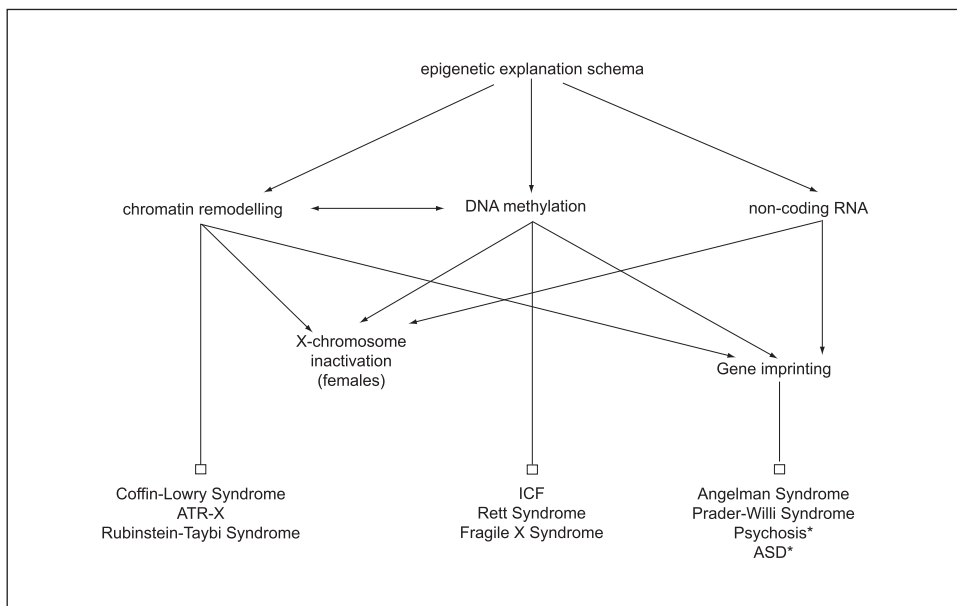


Figure 3. Hierarchy of schemas for epigenetic diseases. Solid arrows indicate causal relations. Square arrows indicate examples of mental disorders resulting from improper functioning of the connected epigenetic mechanism or system of regulation. ATR-X: Alpha-thalassemia/mental retardation syndrome, X-linked. ICF: Immunodeficiency-centromeric instability-facial anomalies syndrome. ASD: Autism Spectrum Disorders. * Indicates disorders with a recently proposed role for epigenetics that has not been as well characterized. Most of these conditions are discussed in Tsankova.³⁴

Disorders with the most well characterized epimutations are those that are concerned with the epigenetic system of genetic imprinting. For imprinted genes, the environmental input that affects gene expression is as simple as whether a given region of chromatin was inherited

³³ Reviewed in TSANKOVA, N. M., RENTHAL, W., KUMAR, A. and NESTLER, E. J., "Epigenetic Regulation in Psychiatric Disorders," *passim*.

³⁴ Cf. "Epigenetic Regulation in Psychiatric Disorders," *passim*.

paternally or maternally. Since imprinted genes are normally expressed from only one chromosome, inheriting two chromosomes from one parent (uniparental disomy), or having a significant deletion of DNA in an imprinted region of only one chromosome can both have drastic consequences. Such errors can result in certain imprinted genes being over expressed or not expressed at all. Improper imprinting of a segment of chromatin at chromosome 15q11-13 has been implicated in two different neurodevelopmental disorders. Exclusively paternal (loss of maternal) expression in this region yields Angelman Syndrome (AS) and exclusively maternal (loss of paternal) expression yields Prader-Willi Syndrome (PWS). Symptoms of AS include cortical atrophy and cognitive abnormalities, while symptoms of PWS include mild mental retardation and endocrine abnormalities.³⁵ Crespi also proposes that alterations in genetic imprinting have played a central role in the evolution of a wide variety of mental illness.³⁶ He proposes that imprinting errors favouring maternal expression of genes is associated with psychotic spectrum conditions, while imprinting errors favouring paternal expression of genes is associated with autism spectrum conditions.

Another well understood disorder where normal functioning of an epigenetic modification is disrupted is Rett Syndrome. This progressive neurodevelopmental disorder affects females when they reach 6-18 months of age and is characterized by symptoms such as deceleration of head growth, loss of speech and purposeful hand movements, mental retardation, and some autistic features.³⁷ It is known that mutations in the gene encoding methyl-CpG-binding protein 2 (MeCP2) are often the ultimate cause of Rett Syndrome.³⁸ MeCP2 normally functions to mediate interactions between the two epigenetic mechanisms of DNA methylation and chromatin remodeling. The protein has been shown to have a silencing effect on gene expression,³⁹ but recent evidence suggests that MeCP2 likely also acts as an activator, and loss of transcriptional activation likely accounts for the majority of associated symptoms.⁴⁰ Rett Syndrome is a great example of an epigenetic disease with a clear genetic cause (mutation of MeCP2) as illustrated in the bottom portion of Figure 2.

4.8. Epigenetics in Complex Mental Illnesses

In general, scientists use two basic criteria to determine if epigenetics might play a role in the etiology of complex disease. 1) An unexpected change or alteration in gene expression

³⁵ See DAVIES, W., ISLES, A. R. and WILKINSON, L. S., "Imprinted Gene Expression in the Brain," *Neuroscience & Biobehavioral Reviews*, v. 29, n. 3, (2005), pp. 421-430.

³⁶ Cf. CRESPI, B., "Genomic Imprinting in the Development and Evolution of Psychotic Spectrum Conditions," *Biological Reviews of the Cambridge Philosophical Society*, v. 83, n. 4, (2008), pp. 441-493.

³⁷ Cf. CHAHROUR, M. and ZOGHBI, H. Y., "The story of Rett Syndrome: From Clinic to Neurobiology," *Neuron*, v. 56, n. 3, (2007), pp. 422-437.

³⁸ Cf. AMIR, R. E., VAN DEN VEYVER, I. B., WAN, M., TRAN, C. Q., FRANCKE, U. and ZOGHBI, H. Y., "Rett Syndrome is Caused by Mutations in X-linked MECP2, Encoding Methyl-CpG-Binding Protein 2," *Nature Genetics*, v. 23, n. 2, (1999), pp. 185-188.

³⁹ See NIKITINA, T., GHOSH, R. P., HOROWITZ-SCHERER, R. A., HANSEN, J. C., GRIGORYEV, S. A. and WOODCOCK, C. L., "MeCP2-Chromatin Interactions Include the Formation of Chromatosome-like Structures and are Altered in Mutations Causing Rett Syndrome," *The Journal of Biological Chemistry*, v. 282, n. 38, (2007), pp. 28237-28245; and NIKITINA, T., SHI, X., GHOSH, R. P., HOROWITZ-SCHERER, R. A., HANSEN, J. C. and WOODCOCK, C. L., "Multiple Modes of Interaction Between the Methylated DNA Binding Protein MeCP2 and Chromatin," *Molecular and Cellular Biology*, v. 27, n. 3, (2007), pp. 864-877.

⁴⁰ Discussed in DELCUVE, G. P., RASTEGAR, M. and DAVIE, J. R., "Epigenetic Control," *Journal of Cellular Physiology*, v. 219, n. 2, (2009), pp. 243-250.

associated with the diseased state. 2) Evidence of one or more epigenetic mechanisms mediating this change. These criteria have been met for several complex mental illnesses such as autism spectrum disorders (ASD), major depressive disorder (MDD), schizophrenia, and Alzheimer's. The first two of these will be discussed here.

The neurodevelopmental disorders mentioned above are categorically similar to ASD. Lasalle has proposed a "Rosetta Stone" approach to understanding possible epigenetic aspects of ASD based on less complex disorders that clearly involve epigenetics such as Rett Syndrome.⁴¹ LaSalle has revealed that MeCP2 expression is often reduced in the frontal cortex of ASD patients despite any detectable genetic defects. This reduction of expression has been linked to abnormal methylation of the MeCP2 promoter.⁴² Improper expression of MeCP2 has been shown to induce lower UBE3A and GABRB3 gene expression that likely contributes to the etiology of ASD.⁴³ In addition to MeCP2 mutations as candidates to explain the etiology of ASD, the epigenetic system of genetic imprinting may also play a role since between 2% and 42% of AS and PWS patients could also be diagnosed for ASD.⁴⁴ Future research is being conducted to determine how environmental agents such as bisphenol A (BPA) might contribute to abnormal methylation in mice and, together with defects in MeCP2 expression, might contribute to ASD.

Major depression is a serious disorder that is estimated to affect 16.2% of Americans at some point in their life.⁴⁵ After years of research looking for markers of genetic susceptibility there is still a great deal of uncertainty concerning etiological risk factors for depression and an absence of any detailed mechanisms.⁴⁶ Mill and Petronis suggest that revealing a potential epigenetic layer of the etiology of MDD might account for several unexplained aspects of the complex disease.⁴⁷ First, there exists a great deal of divergence between two genetically identical monozygotic (MZ) twins when it comes to MDD. While such differences have traditionally been attributed to their non-shared environment, there is evidence that epigenetic differences between MZ twins might accumulate over time in a random fashion or due to environmental factors.⁴⁸ In this way, epigenetics might account for a lack of convincing evidence as to the specific environmental

⁴¹ Cf. LASALLE, J. M., HOGART, A. R. and THATCHER, K. N., "Rett Syndrome: A Rosetta Stone for Understanding the Molecular Pathogenesis of Autism," *International Review of Neurobiology*, v. 71, (2005), pp. 131-165.

⁴² See NAGARAJAN, R. P., HOGART, A. R., GWYE, Y., MARTIN, M. R. and LASALLE, J. M., "Reduced MeCP2 Expression is Frequent in Autism Frontal Cortex and Correlates with Aberrant MECP2 Promoter Methylation," *Epigenetics*, v. 1, n. 4, (2006), pp. e1-11.

⁴³ Cf. SAMACO, R. C., HOGART, A. R. and LASALLE, J. M., "Epigenetic Overlap in Autism-Spectrum Neurodevelopmental Disorders: MECP2 Deficiency Causes Reduced Expression of UBE3A and GABRB3," *Human Molecular Genetics*, v. 14, n. 4, (2005), pp. 483-492.

⁴⁴ Cf. LASALLE, J. M., HOGART, A. R. and THATCHER, K. N., "Rett Syndrome: A Rosetta Stone for Understanding the Molecular Pathogenesis of Autism," *passim*.

⁴⁵ Cf. MURRAY, C. J. and LOPEZ, A. D., "Global Mortality, Disability, and the Contribution of Risk Factors: Global Burden of Disease Study," *Lancet*, v. 349, n. 9063, (1997), pp. 1436-1442.

⁴⁶ Cf. MILL, J. and PETRONIS, A., "Molecular Studies of Major Depressive Disorder: The Epigenetic Perspective," *Molecular Psychiatry*, v. 12, n. 9, (2007) pp. 799-814.

⁴⁷ Cf. MILL, J. and PETRONIS, A., "Molecular Studies of Major Depressive Disorder: The Epigenetic Perspective," *passim*.

⁴⁸ Cf. FRAGA, M. F., BALLESTAR, E., PAZ, M. F., ROPERO, S., SETIEN, F., BALLESTAR, M. L., HEINE-SUNER, D., CIGUDOSA, J. C., URIOSTE, M., BENITEZ, J., BOIX-CHORNET, M., SANCHEZ-AGUILERA, A., LING, C., CARLSSON, E., POULSEN, P., VAAG, A., STEPHAN, Z., SPECTOR, T. D., WU, Y. Z., PLASS, C. and ESTELLER, M., "Epigenetic Differences Arise During the Lifetime of Monozygotic Twins," *Proceedings of the National Academy of Sciences of the USA*, v. 102, n. 30, (2005), pp. 10604-10609.

risk factors for MDD, since differences between MZ twins would be accounted for by diverging epigenomes rather than the non-shared environment. Second, the possibility of transgenerational epigenetic inheritance may explain why it has been difficult to identify specific genes associated with MDD despite its high heritability, since it may not be specific sequences of DNA that confer the risk, but rather certain patterns of expression. Third, epigenetics would provide the mechanistic link needed to understand several reports of specific gene-environment interaction that might contribute to the development of MDD. Fourth, the finding that hormones have been shown to affect both chromatin remodeling and DNA methylation might provide way to explain the high prevalence of MDD among females. Fifth, genetic imprinting may be the mechanism of several parental origin effects reported for MDD.⁴⁹

Some of the best evidence in support of a role for epigenetics in both the onset and treatment of MDD comes from a mouse condition analogous to human depression known as chronic social defeat stress.⁵⁰ In this model, exposure to an aggressor brings about lasting changes in the behaviour of the mouse including social avoidance. While acute treatment with the antidepressant imipramine is insufficient to alleviate these symptoms, chronic treatment is effective in doing so.⁵¹ This is consistent with a slow response to antidepressants that act to increase levels of certain neurotransmitters in humans, and suggests that some downstream process must also be involved in MDD. In the mouse, chronic defeat stress causes decreased expression of two splice variants of brain-derived neurotrophic factor (*Bdnf*) in the hippocampus.⁵² This was mediated by an increase in H3-K27 dimethylation (a repressive modification) specifically at *Bdnf* promoters. This modification was long lasting and not reversed by antidepressant treatment. However, chronic treatment with imipramine induced H3 acetylation and H3-K4 methylation (activating modifications) at the same promoters. This was achieved by down regulating *Hdac5* expression, and the same effect was achieved using the HDAC inhibitor sodium butyrate.⁵³ This is a very clear case of epigenetic mechanisms mediating the onset and alleviation of symptoms in a mouse model of mental illness.

More evidence of a role for epigenetics in the pathogenesis of MDD comes from post mortem samples of suicide victims. Expression of the epigenetic component DNMT was altered in several

⁴⁹ See CSORDAS, A., PUSCHENDORF, B. and GRUNICKE, H., "Increased Acetylation of Histones at an Early Stage of Oestradiol-Mediated Gene Activation in the Liver of Immature Chicks," *Journal of Steroid Biochemistry*, v. 24, n. 1, (1986), pp. 437-442; PASQUALINI, J. R., MERCAT, P. and GIAMBIAGI, N., "Histone Acetylation Decreased by Estradiol in the MCF-7 Human Mammary Cancer Cell Line," *Breast Cancer Research and Treatment*, v. 14, n. 1, (1989), pp. 101-105; and YOKOMORI, N., MOORE, R. and NEGISHI, M., "Sexually Dimorphic DNA Demethylation in the Promoter of the *Slp* (sex-limited protein) Gene in Mouse Liver," *Proceedings of the National Academy of Sciences of the USA*, v. 92, n. 5, (1995), pp. 1302-1306.

⁵⁰ Cf. TSANKOVA, N. M., RENTHAL, W., KUMAR, A. and NESTLER, E. J., "Epigenetic Regulation in Psychiatric Disorders," *passim*; and BERTON, O., McCLUNG, C. A., DILEONE, R. J., KRISHNAN, V., RENTHAL, W., RUSSO, S. J., GRAHAM, D., TSANKOVA, N. M., BOLANOS, C. A., RIOS, M., MONTEGGIA, L. M., SELF, D. W. and NESTLER, E. J., "Essential Role of BDNF in the Mesolimbic Dopamine Pathway in Social Defeat Stress," *Science*, v. 311, n. 5762, (2006), pp. 864-868.

⁵¹ See BERTON, O., McCLUNG, C. A., DILEONE, R. J., KRISHNAN, V., RENTHAL, W., RUSSO, S. J., GRAHAM, D., TSANKOVA, N. M., BOLANOS, C. A., RIOS, M., MONTEGGIA, L. M., SELF, D. W. and NESTLER, E. J., "Essential Role of BDNF in the Mesolimbic Dopamine Pathway in Social Defeat Stress," *passim*; and TSANKOVA, N. M., BERTON, O., RENTHAL, W., KUMAR, A., NEVE, R. L. and NESTLER, E. J., "Sustained Hippocampal Chromatin Regulation in a Mouse Model of Depression and Antidepressant Action," *Nature Neuroscience*, v. 9, n. 4, (2006), pp. 519-525.

⁵² Cf. TSANKOVA, N. M., BERTON, O., RENTHAL, W., KUMAR, A., NEVE, R. L. and NESTLER, E. J., "Sustained Hippocampal Chromatin Regulation in a Mouse Model of Depression and Antidepressant Action," *passim*.

⁵³ See "Sustained Hippocampal Chromatin Regulation in a Mouse Model of Depression and Antidepressant Action," *passim*; SCHROEDER, F. A., LIN, C. L., CRUSIO, W. E. and ARKARIAN, S., "Antidepressant-Like Effects of the Histone Deacetylase Inhibitor, Sodium Butyrate, in the Mouse," *Biological Psychiatry*, v. 62, n. 1, (2007), pp. 55-64.

brain regions including the frontopolar cortex of suicide victims relative to individuals who died suddenly of other causes. This is evidence of altered gene expression associated with the suicide brain mediated by DNA methylation. The effects of altered DNMT expression included three CpG sites in the promoter region of a GABA receptor subunit gene that were found to be hypermethylated relative to control subjects causing decreased expression.⁵⁴

5. CONCLUSION

We have gone into detail on the new epigenetic approach to explanations of mental illness for two reasons. First, this development illustrates the increasing complexity of multilevel explanations of psychiatric disorders. Social and molecular causes can interact in part because environments affect how genes are activated to produce or not to produce different proteins. Second, epigenetics appears to be introducing a new way of classifying diseases in terms of underlying complex causation and hence may be introducing an important kind of conceptual change in psychiatry. The development of scientific medicine in the 19th and 20th centuries provided a very useful set of categories for causally classifying diseases as infectious, nutritional, autoimmune, and so on.⁵⁵ But some diseases such as arteriosclerosis defy such easy categorizations and can only be identified as multifactorial, a category that also now seems appropriate for most mental illnesses.

At the beginning of this paper, we described some of the major conceptual changes that have taken place in the history of the scientific investigation of mental illness. These included the shift from religious to biological explanations, the rise and fall of psychoanalytic explanations, and major advances in the neurochemical basis of many disorders. We argued, however, that the latter advances do not obviate attention to psychological and social factors, rendering mental illnesses as best classified as multifactorial diseases. The new field of epigenetics provides dramatic details about how such causality, ranging from the social to the molecular, might work. Clearly, we should expect future conceptual changes in psychiatry.⁵⁶

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⁵⁴ Cf. POULTER, M. O., DU, L., WEAVER, I. C., PALKOVITS, M., FALUDI, G., MERALI, Z., SZYF, M. and ANISMAN, H., "GABAA Receptor Promoter Hypermethylation in Suicide Brain: Implications for the Involvement of Epigenetic Processes," *Biological Psychiatry*, v. 64, n. 8, (2008), pp. 645-652.

⁵⁵ Cf. THAGARD, P., *How Scientists Explain Disease*, *passim*.

⁵⁶ Acknowledgements. This research has been supported by the Natural Sciences and Engineering Research Council of Canada.

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V

From Medicine to New Sciences

9. Causation in Medicine

10. Conceptual Revolutions in Information Science: The Case of Web

CAUSATION IN MEDICINE

Brendan Clarke

1. INTRODUCTION: CAUSATION AND CONCEPTUAL CHANGE VIA CERVICAL CANCER

In this paper, I offer one example of conceptual change. Specifically, I contend that the discovery that viruses could cause cancer represents an excellent example of branch jumping, one of Thagard's nine forms of conceptual change.¹ Prior to about 1960, cancer was generally regarded as a degenerative, chronic, non-infectious disease. Cancer causation was therefore usually held to be a gradual process of accumulating cellular damage, caused by relatively non-specific component causes, acting over long periods of time. Viral infections, on the other hand, were generally understood to be acute processes, whereby single, specific and necessary causal agents acted alone to produce disease.

However, during the 1960s and 1970s, a number of cancers were discovered to have an infectious aetiology. Of particular note were two — Burkitt's lymphoma and cervical cancer — which I will discuss in detail later in this piece. Together, these discoveries led, in the short term, to a tentative aetiological reclassification of some types of cancer as infectious diseases and, in the longer term, to a full-blown reclassification of cancer as an aetiological disease branch in its own right. This process of reclassification forms the empirical basis for my concluding remarks on the influence of classification upon causation in medicine. Through this, I aim to demonstrate that conceptual change, far from being a purely abstract concern of the philosopher of science, is of substantial import to scientific practitioners.

2. BURKITT'S LYMPHOMA (BL)

BL is an extranodal B-cell lymphoma which occurs primarily in young children living in sub-Saharan Africa.² It was first described in 1958 by Denis Burkitt in the following way. First, while malignant tumours of the jaw are generally rare in children, they appeared to be unusually common in parts of Uganda. In fact, they were by far the commonest malignant disease of childhood.³ These jaw tumours appeared to be part of a wider clinical syndrome, with histologically similar material also found in other anatomical sites, including within the abdomen. This syndrome was strikingly unusual in three respects. First, despite the high

¹ Cf. THAGARD, P., *Conceptual Revolutions*, Princeton University Press, Princeton, NJ, 1992.

² Cf. HARRIS, N. L. ET AL., "World Health Organization Classification of Neoplastic Diseases of the Hematopoietic and Lymphoid Tissues: Report of the Clinical Advisory Committee Meeting-Airlie House, Virginia, November 1997," *Journal of Clinical Oncology*, v. 17, n. 12, (1999), pp. 3835-3849.

³ Cf. BURKITT, D., "A Sarcoma Involving the Jaws in African Children," *The British Journal of Surgery*, v. 46, n. 197, (1958), pp. 218-223.

incidence of the disease in Uganda, it was unknown in other parts of the world, suggesting the existence of some particular geographical distribution. Second, the disease appeared to affect only young children, in sharp contrast to most tumours. Third, the disease affected several sites of the body simultaneously, including multiple sites within the jaw and within the abdomen. For this pathogenic mechanism to be the case, a novel process of either simultaneous, multifocal oncogenesis occurring in both jaw and abdomen, or a mechanism of sudden metastasis by unknown means, would be required. Together, these three anomalies suggested the action of an unusual causal mechanism underlying the disease.

The initial research direction was this. First, the clinical picture was developed through the investigation of further instances of the disease. While this led to numerous minor refinements, no substantial developments in understanding the aetiology of the disease were made. Second, the epidemiology of the tumour was systematically investigated. Importantly, the geographical limits of the disease were sought by conducted a postal survey of African hospitals, asking for sightings of the distinctive clinical features of the lymphoma.⁴ This survey was sufficiently successful to allow the mapping of tumour cases across large parts of Africa. As a consequence of this mapping exercise, the lymphoma syndrome was seen to occur in a belt across the continent, spanning the equator, with a tail running down the east coast and sparing the northern and southern extremities.⁵ The islands of Zanzibar and Pemba, lying off the coast of Tanganyika (now incorporated into Tanzania) were spared entirely.

Furthermore, there appeared to be areas within this “lymphoma belt” in which the tumour did not occur or, at least, occurred with greatly reduced frequency. This distribution led to enquiries into the unifying factors common to the regions of high tumour incidence. It was noted that this distribution could be mirrored by the consideration of certain climatic factors. For instance, eliminating all areas where the mean temperature fell below 15°C at any time of year, over 1500m altitude, and where mean annual rainfall was less than 750mm, gave a map which was “almost identical with the map of tumour distribution.”⁶

This geographic distribution suggested the activity of some causally significant entity which depended on climatic factors, for instance flora or fauna. Two arthropods of known medical importance had distributions similar to that of BL. The first was the tsetse fly (*Glossina* spp.), the insect vector of African trypanosomiasis, while the second was the *Anopheles* mosquito, the vector of malaria. Certain recent outbreaks of viral disease in the region, in turn, suggested that these insects might act as vectors for unknown viruses. Could an insect-vector virus be the cause of BL?

While the viral hypothesis was initially strengthened by the presence, under electron microscopy, of changes suggestive of viral activity in BL tumour cells, no virus itself was detectable, although a wide range of techniques were used, including cell cultures, infection of fertilized hens eggs and inoculation of material into newborn mice.⁷ When the cells of BL were

⁴ BURKITT, D. and WRIGHT, D., “A Lymphoma Syndrome in Tropical Africa with a Note on Histology, Cytology, and Histochemistry,” *International Review of Experimental Pathology*, v. 2, (1963), pp. 67-138.

⁵ BURKITT, D., “Observations on the Geography of Malignant Lymphoma,” *East African Medical Journal*, v. 38, (1961), pp. 511-514.

⁶ Cf. BURKITT, D., “Observations on the Geography of Malignant Lymphoma,” pp. 511-514.

⁷ Cf. EPSTEIN, M. A., “The Origins of EBV Research: Discovery and Characterization of the Virus,” in ROBERTSON E. S. (ed.), *Epstein-Barr Virus*, Caister Academic Press, Norfolk, 2005, pp. 1-14.

grown in cell culture, however, a different story developed. On the 24th of Feb 1964, samples of the first cell line derived from BL were examined using thin section electron microscopy. The findings were exciting — with “...unequivocal virus particles in a cultured BL cell in the very first grid square to be searched.” These virus-like particles were subsequently rapidly detected in other BL cell lines.⁸

These virus-like particles seen on electron microscopy were the first detection of a new herpesvirus, which later became known as the Epstein-Barr virus (EBV) after its discoverers.⁹ Immunofluorescence testing revealed that viral antigens were immunologically reactive against the serum of patients with Burkitt’s lymphoma, and against BL cells. As might be expected, the extent of immunofluorescence correlated with virus particles as seen using electron microscopy.¹⁰ Mystifyingly, though, despite the relatively specific immunological response obtained in cases of BL, it was also immunologically reactive against the sera of non-BL individuals, including leukaemia patients,¹¹ individuals with nasopharyngeal carcinomas¹² and, most confusingly of all, against many normal North American control individuals.¹³ This suggested that infections with EBV was far more common in non-BL populations than might be expected if EBV were really the causal agent of BL.

So if EBV was to be the cause of BL, an explanation for its presence in so many individuals without the disease was required. Could it be the case that, while EBV caused BL, it also caused a range of other diseases? Perhaps the most significant development in this field arose as following. While conducting a series of surveys for EBV antibodies using sera from a variety of paediatric illnesses of unknown, but presumptively viral, aetiology, one researcher by chance developed Infectious Mononucleosis (IM; glandular fever). It was discovered that, following this infection, her leukocytes became capable of growing in cell culture, a property they had not possessed when tested before the development of the disease. While she initially did not display antibodies to EBV, from the outset her cultured cells expressed EBV antigens, and contained the chromosomal abnormalities characteristic of BL.¹⁴ When further sera from IM patients were examined, they were all found to be strongly positive for anti-EBV antibodies. This led to the conclusion that IM was causally related to EBV:

⁸ For example, PULVERTAFT, J. V., “Cytology of Burkitt’s Tumour (African Lymphoma),” *The Lancet*, v. 283, n. 7327, (1964), pp. 238-240; EPSTEIN, M. A., BARR, Y. M. and ACHONG, B. G., “A Second Virus-Carrying Tissue Culture Strain (EB2) of Lymphoblasts from Burkitt’s Lymphoma,” *Pathologie-Biologie*, v. 12, (1964), pp. 1233-1234; EPSTEIN, M. A., BARR, Y. M. and ACHONG, B. G., “Studies with Burkitt’s Lymphoma,” *The Wistar Institute Symposium Monograph*, v. 4, (1965), pp. 69-82; and STEWART, S. E., LOVELACE, E., WHANG, J. J. and NGU, V. A., “Burkitt Tumor: Tissue Culture, Cytogenetic and Virus Studies,” *Journal of the National Cancer Institute*, v. 34, (1965), pp. 319-327.

⁹ EBV is a B-lymphotropic γ -herpesvirus. It infects B-cells, and is capable of immortalising them. The virus is highly prevalent in adult human populations worldwide, with up to 90% of adults displaying evidence of infection.

¹⁰ Cf. HENLE, G. and HENLE, W., “Immunofluorescence in Cells Derived from Burkitt’s Lymphoma,” *Journal of Bacteriology*, v. 91, n. 3, (1966), pp. 1248-1256.

¹¹ Cf. HENLE, G. and HENLE, W., “Immunofluorescence in Cells Derived from Burkitt’s Lymphoma,” pp. 1248-1256.

¹² Cf. HENLE, W., HENLE, G., HO, H. C., BURTON, P., CACHIN, Y., CLIFFORD, P., ET AL., “Antibodies to Epstein-Barr Virus in Nasopharyngeal Carcinoma, Other Head and Neck Neoplasms, and Control Groups,” *Journal of the National Cancer Institute*, v. 44, n. 1, (1970), pp. 225-231.

¹³ About 30% of children and 90% of adults showed immunological evidence of past infection with EBV. HENLE, G. and HENLE, W., “Immunofluorescence in Cells Derived from Burkitt’s Lymphoma,” *passim*.

¹⁴ Cf. HENLE, G., HENLE, W. and DIEHL, V., “Relation of Burkitt’s Tumor-Associated Herpes-Type Virus to Infectious Mononucleosis,” *Proceedings of the National Academy of Sciences of the United States of America*, v. 59, n. 1, (1968), pp. 94-101.

“Patients with infectious mononucleosis regularly develop antibodies to the herpes-type virus (EBV) found in cultures derived from Burkitt’s tumors or other cells of the hematopoietic system. ... The epidemiology of IM and the seroepidemiology of EBV share many features. Thus, it appears that EBV, or a close relative of it, is the cause of IM. This conclusion does not preclude the possibility that EBV might also be involved, either directly or indirectly, in the etiology of Burkitt’s lymphoma.”¹⁵

This probable aetiologic relationship could therefore explain the serological evidence of past EBV infection in otherwise healthy individuals. However, the causal mechanism linking BL and EBV was still rather incomplete by the early 1970s. There was, therefore, much resistance to it until the completion of various epidemiological studies demonstrating the increased risk of BL in populations with high levels of anti-EBV antibodies. One important example of these types of investigation was the large prospective seroepidemiological study in the lymphoma belt that began in 1971.¹⁶ It followed 42,000 children from birth to 8 years old in the West Nile District of Uganda. Serum samples were taken at enrolment, and enrolled children were then monitored for the development of BL. In total, 14 of the 42,000 participants developed the disease during the lifetime of the trial. It was shown that affected individuals had higher levels of anti-EBV antibodies than controls at baseline. When this finding was combined with earlier work that populations at high BL risk tended to acquire anti-EBV antibodies at a younger age than individuals in populations at low risk, a mechanism of differential pathogenesis began to be developed.¹⁷ In broad terms, individuals who became infected with EBV young were at risk of developing BL, while individuals becoming infected later in life tended to develop IM.¹⁸

So BL is one example of human viral oncogenesis that contributed significantly to the conceptual change occurring in cancer causation. The causal arguments above show modifications to, not only arguments regarding cancer causation, but also to those regarding the causation of viral illnesses more widely. However, the generalisability of these modifications appears doubtful. For one, Burkitt’s lymphoma is a rather atypical tumour in several respects. It is rather uncommon, and occurs in a particular distribution — both geographically, restricted to a narrow band of sub-Saharan Africa, and in a narrow range of susceptible ages — really only between 5 and 8 years. For another, the causal relationship between EBV and its range of clinical manifestations remains highly complex. In detail, it is not at all clear what other factors predispose towards the different manifestations of the same virus in different populations. The case of BL and EBV therefore presented something akin to an oddity, rather than a revolution in cancer causation. It would take the discovery of viral oncogenesis in a much more common setting before this conceptual change really took hold.

¹⁵ HENLE, G., HENLE, W. and DIEHL, V., “Relation of Burkitt’s Tumor-Associated Herpes-Type Virus to Infectious Mononucleosis,” p. 101.

¹⁶ Cf. DE-THÉ, G., GESER, A., DAY, N. E., TUKEI, P. M., WILLIAMS, E. H., BERI, D. P. ET AL., “Epidemiological Evidence for Causal Relationship between Epstein-Barr Virus and Burkitt’s Lymphoma from Ugandan Prospective Study,” *Nature*, v. 274, n. 5673, (1978), pp. 756-761.

¹⁷ See, for example, HENLE, G., HENLE, W., CLIFFORD, P., DIEHL, V., KAFUKO, G. W., KIRYA, B. G. ET AL., “Antibodies to Epstein-Barr Virus in Burkitt’s Lymphoma and Control Groups,” *Journal of the National Cancer Institute*, v. 43, n. 5, (1969), pp. 1147-1157.

¹⁸ Although this branch of the mechanism remains incomplete, and the interactions of other risk factors with early-life EBV infection in the genesis of BL is poorly understood.

3. CERVICAL CANCER

A much more surprising candidate for viral oncogenesis was cervical cancer. Unlike Burkitt's lymphoma, cervical cancer is a much more typical tumour: it occurs relatively commonly, has a worldwide distribution and (generally) increases in incidence with age. Before about 1960, cervical cancer was believed to have similar risk factors to other malignant diseases: "Long-continued irritation and chronic inflammation are probably the conditions which pave the way for the development of the new growth."¹⁹

These risk factors were thought typical for a disease of the degenerative-chronic type. However, it later emerged that the risk factors for cervical cancer were similar to those of an infectious disease. For instance, as one of the major reviews of the epidemiology and aetiology of cervical cancer rather bluntly put it:²⁰ "The cancer patient is characterised by more marital misadventures, divorce and separation, more pre-marital coitus and deliveries and more sexual partners."²¹

A great deal of sound epidemiologic data appeared to support this thesis, with a complex web of socioeconomic factors, particularly those indicating social class, marital and sexual habits and features of male sexual partners, modifying the risk of developing the disease.²² However, no specific mechanism was developed to explain these phenomena. Instead, background plausibility assumptions played the major role in deciding which factors were causal, and which were confounders — that is, which factors were merely correlated markers of genuinely causal ones. So, for instance, while investigating the correlation between marriage and the development of cervical cancer, Lombard and Potter noted that a direct causal link was implausible: "...no one would consider the mere ceremony of marriage to have a bearing on the causation of the disease."²³

That is not to say there was no relevant investigation of the mechanism of oncogenesis. Some research — particularly into the mechanism of male factors in cervical cancer — attempted to investigate questions raised by epidemiological research.²⁴ But in general, epidemiological research was not coupled to a corresponding laboratory program of the mechanism of cancer causation.

That is until the discovery of human viral oncogenesis. A viral infection causing cervical cancer could provide a means of unifying and explaining these risk factors, and, by about 1970,

¹⁹ DEEVER, J. B. and REIMANN, S. P., "Cancer of the Uterus: With General Remarks on the Pathologic Aspects of Cancer of the Uterus," *Annals of Surgery*, v. 94, n. 3, (1931), p. 383.

²⁰ Cf. AITKEN-SWAN, J. and BAIRD, D., "Cancer of the Uterine Cervix in Aberdeenshire. Epidemiological Aspects," *British Journal of Cancer*, v. 20, n. 4, (1966), pp. 624-641.

²¹ AITKEN-SWAN, J. and BAIRD, D., "Cancer of the Uterine Cervix in Aberdeenshire. Aetiological Aspects," *British Journal of Cancer*, v. 20, n. 4, (1966), p. 656.

²² In brief, these factors were:

Risk factors: low socioeconomic class, marriage, sexual intercourse, multiple sexual partners, employment as prostitutes, infection with syphilis.

Protective factors: Jewish or Muslim faith, abstinence from sex, circumcision of male partner, cleanliness of male partner, use of barrier contraception.

See, for instance, ELLIOTT, R., "On the Prevention of Carcinoma of the Cervix," *The Lancet*, v. 1, n. 7327, (1964), pp. 231-235, for a review.

²³ LOMBARD, H. and POTTER, E., "Environmental Factors in the Etiology of Cancer," *Acta Unio Internationalis Contra Cancrum*, v. 6, (1950), p. 1330.

²⁴ For example, both PLAUT, A. and KOHN-SPEYER, A., "The Carcinogenic Action of Smegma," *Science*, v. 105, n. 2728, (1947), pp. 391-392; and PRATT-THOMAS, H., HEINS, H. C., LATHAM, E., DENNIS, E. J. and MCLIVER, F. A., "The Carcinogenic Effect of Human Smegma: An Experimental Study. I. Preliminary Report," *Cancer*, v. 9, n. 4, (1955), pp. 671-680, showed experimentally that exposure to smegma could act as an initiation of carcinogenesis.

cervical cancer commonly believed to be caused by a virus. The formerly known social factors were now generally explained as acting by modifying the chances of a woman contracting it. Interestingly, though, this emergent research program was not a result of finding the correct causal virus. We now know that cervical cancer is caused by infection with certain strains of the human papillomavirus (HPV). However, this was not known until the 1980s. In fact, much of this earlier research suggested that herpes simplex virus (HSV), responsible for, amongst other things genital herpes infections, was responsible.²⁵ This seemed highly plausible: herpes viruses were known to be capable of causing cancers — for instance, the causal virus of Burkitt's lymphoma is a type of herpes virus; the epidemiology of the virus was consistent with the existing evidence and herpes infections and cervical cancer were rather well correlated on an individual case basis. In fact, the evidence linking HSV and cervical cancer was rather impressive.

To give a summary of this evidence, HSV is a commensal organism, likely to grow in the female reproductive tract.²⁶ In fact, it was known to be responsible for genital herpes infections. Thus, it was also known to be transmitted through sexual intercourse, offering a possible explanation for some cervical cancer risk factors. These included the role of first coitus, marriage or pregnancy, at an early age, the role of multiple sexual partners or promiscuity in increasing disease incidence, and the finding that women of low socioeconomic status were at higher risk of cervical cancer than wealthy. Second, herpesviruses were known to be implicated in other malignant diseases. Not only was the causal agent of BL a herpesvirus, but many non-human animals were known to suffer from herpes-associated malignant diseases. Third, there was an apparent serological association between the virus and the cancer. Antibodies against one type of HSV (HSV2) were present in prostitutes (who have a very high rate of cervical cancer) more than twice as often as in control populations and four times as often in women with cervical cancer than controls.²⁷ Fourth, HSV was known to be capable of causing chromosomal abnormalities *in vitro* in both animal and human cells, similar to those known to be associated with many sorts of cancer.²⁸ Fifth, it also became apparent that fragments of HSV DNA could be directly detected in cervical cancer cell, suggesting some specific role in pathogenesis.²⁹

These supporting pieces of evidence were highly plausible, but did not constitute a causal mechanism for cervical cancer. Attempts to produce an experimental model of disease in animals were problematic. Early experimental attempts to induce tumours in animals by inoculation

²⁵ HSV as the causal agent of cervical cancer really began in earnest in 1966. See NAIB, Z. M., NAHMIAS, A. J. and JOSEY, W. E., "Cytology and Histopathology of Cervical Herpes Simplex Infection," *Cancer*, v. 19, n. 7, (1966), pp. 1026-1031.

²⁶ Summary derived from ALEXANDER, E., "Possible Etiologies of Cancer of the Cervix Other Than Herpesvirus," *Cancer Research*, v. 33, n. 6, (1973), pp. 1485-1490.

²⁷ Cf. RAWLS, W. E., TOMPKINS, W. A., FIGUEROA, M. E. and MELNICK J. L., "Herpesvirus Type 2: Association with Carcinoma of the Cervix," *Science*, v. 161, n. 847, (1968), pp. 1255-1256; and RAWLS, W. E., TOMPKINS, W. A. and MELNICK, J. L., "Serological Association between Herpesvirus Type 2 and Cervical Cancer," *Bacteriological Proceedings*, v. 1969, (1969), p. 178.

²⁸ Cf. HAMPAR, B. and ELLISON, S. A., "Cellular Alterations in the MCH Line of Chinese Hamster Cells Following Infection with Herpes Simplex Virus," *Proceedings of the National Academy of Sciences of the United States of America*, v. 49, (1963), pp. 474-480

²⁹ HSV2 nucleic acids were recovered, in a single case, from cervical cancer tissue samples. However, this finding was not replicable, and it remained the case that HSV genetic material could generally only be detected from cells grown *in vitro* cell cultures. Cf. FRENKEL, N., ROIZMAN, B., CASSAI, E. and NAHMIAS, A., "A DNA Fragment of Herpes Simplex 2 and Its Transcription in Human Cervical Cancer Tissue," *Proceedings of the National Academy of Sciences of the United States of America*, v. 69, n. 12, (1972), pp. 3784-3789.

with various herpes simplex strains failed outright.³⁰ Later animal inoculation experiments too were equivocal, although some of them displayed a slight apparent effect of HSV2 inoculation on tumour development. In both cases this work was complicated by the very high subject mortality caused by the lytic effects of HSV. I might also speculate that a general unwillingness to publish negative findings makes it likely that there were even more unsuccessful attempts to induce cervical tumours using HSV than the literature reveals.

Similar experiments using *in vitro* cell cultures were more successful. For instance, cells *in vitro* could be transformed by incubation with UV-inactivated HSV2. These transformed cells displayed HSV antigens, and were capable of inducing malignant tumour formation when inoculated into animal subjects.³¹ Fragments of HSV nucleic acids were also detectable in these cell lines.³²

Thus the general oncogenic properties of the herpesviruses revealed, in part, by these experiments required some specific demonstration in cervical cancer. However, no publications reporting such findings seem to be extant. It thus was the role of epidemiology to suggest that the herpesvirus hypothesis was mistaken. As with Burkitt's lymphoma, a large prospective seroepidemiological study was undertaken. This involved more than 10,000 women in Prague. While the results of this study showed general agreement between cervical cancer risk and the previously known risk factors,³³ no differences in HSV2 status appeared to exist between matched control subjects and cancer cases.³⁴ Thus this study did not seem to support a causal role for HSV in the development of the cancer. Thus, the role of HSV as a specific, necessary cause of cervical cancer seemed untenable. Instead, HSV was now thought to correlate with a second sexually transmitted agent. Various candidate agents were investigated, including human papillomavirus (HPV).

HPV initially seemed a most unpromising agent, for the simple reason that no detection of the virus had been made in cervical cancer tissue. However, it did seem at least plausible that HPV could have a pathogenic role. For example, various other diseases — including skin warts and the rare, heritable skin disease epidermodysplasia verruciformis — were known to be related to papillomavirus infection. Electron microscopy of material derived from several types of wart revealed strong morphological similarities between the various virus particles.³⁵

³⁰ RAPP, F. and FALK, L., "Study of Virulence and Tumorigenicity of Variants of Herpes Simplex Virus," *Proceedings of the Society for Experimental Biology and Medicine*, v. 116, (1964), pp. 361-365.

³¹ Cf. DUFF, R. and RAPP, F., "Properties of Hamster Embryo Fibroblasts Transformed *In Vitro* after Exposure to Ultraviolet-Irradiated Herpes Simplex Virus Type 2," *Journal of Virology*, v. 8, n. 4, (1971), pp. 469-477.

³² See COLLARD, W., THORNTON, H. and GREEN, M., "Cells Transformed by Human Herpesvirus Type 2 Transcribe Virus-Specific RNA Sequences Shared by Herpesvirus Types 1 and 2," *Nature: New Biology*, v. 243, n. 130, (1973), pp. 264-266.

³³ Cf. VONKA, V., KANKA, J., JELÍNEK, J., SUBRT, I., SUCHNEK, A., HAVRÁNKOVÁ, A. ET AL., "Prospective Study on the Relationship between Cervical Neoplasia and Herpes Simplex Type-2 Virus. I. Epidemiological Characteristics," *International Journal of Cancer*, v. 33, n. 1, (1984), pp. 49-60.

³⁴ Cf. VONKA, V., KANKA, J., HIRSCH, I., ZÁVADOVÁ, H., KRČMÁR, M., SUCHÁNKOVÁ, A. ET AL., "Prospective Study on the Relationship between Cervical Neoplasia and Herpes Simplex Type-2 Virus. II. Herpes Simplex Type-2 Antibody Presence in Sera Taken at Enrollment," *International Journal of Cancer*, v. 33, n. 1, (1984b), pp. 61-66; KRČMÁR, M., SUCHÁNKOVÁ, A., KANKA, J. and VONKA, V., "Prospective Study on the Relationship between Cervical Neoplasia and Herpes Simplex Type 2 Virus. III. Presence of Herpes Simplex Type-2 Antibody in Sera of Subjects Who Developed Cervical Neoplasia Later in the Study," *International Journal of Cancer*, v. 38, n. 2, (1986), pp. 161-165.

³⁵ Cf. ORIEL, J. D. and ALMEIDA, J. D., "Demonstration of Virus Particles in Human Genital Warts," *The British Journal of Venereal Diseases*, v. 46, n. 1, (1970), pp. 37-42.

Similar too was the clinical course of disease seen during experimental or accidental wart transmission experiments. Together, these two features suggested that papillomaviruses could cause both benign and malignant diseases, and were transmissible. Yet the means by which this transmission could occur was unknown. For one, the different known papillomaviruses, despite having similar gross morphologies and genome lengths,³⁶ were antigenically distinct and their genomes showed a good deal of variance when analysed in terms of base composition.³⁷

Both immuno-EM and RNA-hybridisation experiments revealed a significant degree of difference between the papillomaviruses associated with different disease, with material derived from one type of disease appearing to share neither immunological nor genetic characteristics with material derived from others.³⁸ There were important epidemiological questions too. Different papillomavirus diseases in humans (warts, genital warts or laryngeal warts) characteristically occurred at different ages and in different populations. This finding too seemed to count against a strongly unified cause for these diseases.

Were HPV a group of related viruses? Could this explain the different clinical and experimental properties of the (visually identical) viruses? Part of the puzzle was resolved when researchers examined in detail the genomes of papillomaviruses from different types of wart material, when it rapidly became apparent that a number of diverse HPV strains were present. These strains were immunologically distinct, suggesting that, despite the previous lack of detection of the virus in cervical cancer cells, HPV could still be causally implicated:

“The condyloma agent has been entirely neglected thus far in all epidemiological and serological studies relating ... to cervical ... carcinomas. This is particularly unusual in view of the localization of genital warts, their mode of venereal transmission, the number of reports on malignant transition, and the presence of an agent belonging to a well-characterized group of oncogenic DNA viruses.”³⁹

So the discovery that HPV did, in fact, cause cervical cancer required the development of a large number of strain-specific tests for HPV. In fact, it was not until the discovery and cloning of HPV-16 from a cervical cancer tissue sample that HPV could be detected in most cases of cervical cancer.⁴⁰ This newly discovered strain of HPV was highly specific for cervical cancer, and generally could not be detected in other papillomavirus-related disease. A degree of strain variation by geographical region also seemed to be the case, with HPV-16 being detectable in at much higher rates in European cervical cancer samples than those from Africa or South America. A second novel strain, HPV-18, was soon detected in an African cervical cancer

³⁶ See CRAWFORD, L. V. and CRAWFORD, E., “A Comparative Study of Polyoma and Papilloma Viruses,” *Virology*, v. 21, (1963), pp. 258-263.

³⁷ Cf. CRAWFORD, L. V. and CRAWFORD, E., “A Comparative Study of Polyoma and Papilloma Viruses,” pp. 258-263; and LE BOUVIER, G. L., SUSSMAN, M. and CRAWFORD, L. V., “Antigenic Diversity of Mammalian Papillomaviruses,” *Journal of General Microbiology*, v. 45, n. 3, (1966), pp. 497-501.

³⁸ See, e.g. ZUR HAUSEN, H., MEINHOF, W., SCHEIBER, W. and BORNKAMM, G. W., “Attempts to Detect Virus-Specific DNA in Human Tumors. I. Nucleic Acid Hybridizations with Complementary RNA of Human Wart Virus,” *International Journal of Cancer*, v. 13, n. 5, (1974), pp. 650-656.

³⁹ ZUR HAUSEN, H., “Condylomata Acuminata and Human Genital Cancer,” *Cancer Research*, v. 36, n. 2, part 2, (1976), p. 794.

⁴⁰ Cf. DÜRST, M., GISSMANN, L., IKENBERG, H. and ZUR HAUSEN, H., “A Papillomavirus DNA from a Cervical Carcinoma and Its Prevalence in Cancer Biopsy Samples from Different Geographic Regions,” *Proceedings of the National Academy of Sciences of the United States of America*, v. 80, n. 12, (1983), pp. 3812-3815.

sample by similar means to that of HPV-16, which also seemed relatively region-specific.⁴¹ Taken together, HPV-16 and -18 were present in most tested cervical cancer samples. This demonstration of strain-specificity was further support for the causal role of the virus. Unlike the earlier causal candidate HSV, a pathogenic mechanism was rapidly developed linking the virus with the disease.

While I won't attempt a detailed review of it here, it seems worth giving an outline of a few of the major developments. First, it was found that cloned HPV DNA alone was capable of transforming cells *in vitro*.⁴² This process of transformation involved incorporation of the HPV genome into the host genome.⁴³ RNA analysis revealed the expression of a number of non-structural viral proteins in these immortalised cells. These "early" viral proteins appeared causally important in cellular transformation.⁴⁴ In particular, the E6 and E7 proteins appeared to be responsible for modifying cell cycle regulation through a number of specific mechanisms. Acting together, HPV-18 E6 and E7 proteins were found to be necessary and sufficient for cell transformation, *in vitro*, at least.⁴⁵ E6 is necessarily responsible for the maintenance of tumours.⁴⁶ However, acting alone, it also appeared capable of inducing immortalisation in some cell-types, causing cell-cycle deregulation by p53 degradation.⁴⁷ E7, though, acts through interactions with the retinoblastoma gene product pRb, leading to cell-cycle deregulation via disruption of the actions of transcription factor E2F.⁴⁸ Thus, E7 acts as the initiator of cell immortalization.⁴⁹ This process of HPV integration, early protein expression and disruption of cell-cycle regulation was suggested as the mechanism underlying the transformation of cells. These immortalised cells appeared capable too of malignant progression. *In vitro* studies of keratinocytes immortalised by HPV became malignant in a stochastic fashion upon prolonged passage.⁵⁰

⁴¹ Cf. BOSHART, M., GISSMANN, L., IKENBERG, H., KLEINEHEINZ, A., SCHEURLIN, W. and ZUR HAUSEN, H., "A New Type of Papillomavirus DNA, Its Presence in Genital Cancer Biopsies and in Cell Lines Derived from Cervical Cancer," *The EMBO Journal*, v. 3, n. 5, (1984), pp. 1151-1157.

⁴² Cf. CHEN, T. M., PECORARO, G. and DEFENDI, V., "Genetic Analysis of *in Vitro* Progression of Human Papillomavirus-Transfected Human Cervical Cells," *Cancer Research*, v. 53, n. 5, (1993), pp. 1167-1171.

⁴³ Cf. YEE, C., KRISHNAN-HEWLETT, I., BAKER, C. C., SCHLEGEL, R. and HOWLEY, P. M., "Presence and Expression of Human Papillomavirus Sequences in Human Cervical Carcinoma Cell Lines," *The American Journal of Pathology*, v. 119, n. 3, (1985), pp. 361-366.

⁴⁴ Cf. KAUR, P. and McDUGALL, J. K., "Characterization of Primary Human Keratinocytes Transformed by Human Papillomavirus Type 18," *Journal of Virology*, v. 62, n. 6, (1988), pp. 1917-1924.

⁴⁵ Cf. MÜNGER, K., PHELPS, W. C., BUBB, V., HOWLEY, P. M. and SCHLEGEL, R., "The E6 and E7 Genes of the Human Papillomavirus Type 16 Together Are Necessary and Sufficient for Transformation of Primary Human Keratinocytes," *Journal of Virology*, v. 63, n. 10, (1989), pp. 4417-4421.

⁴⁶ Cf. VON KNEBEL DOEBERITZ, M., RITTMÜLLER, C., AENGENEYNDT, F., JANSEN-DÜRR, P. and SPITKOVSKY, D., "Reversible Repression of Papillomavirus Oncogene Expression in Cervical Carcinoma Cells: Consequences for the Phenotype and E6-p53 and E7-pRb Interactions," *Journal of Virology*, v. 68, n. 5, (1994), pp. 2811-2821.

⁴⁷ Cf. SCHEFFNER, M., WERNES, B. A., HUIBREGTSE, J. M., LEVINE, A. J. and HOWLEY, P. M., "The E6 Oncoprotein Encoded by Human Papillomavirus Types 16 and 18 Promotes the Degradation of p53," *Cell*, v. 63, n. 6, (1990), pp. 1129-1136.

⁴⁸ Cf. CHELLAPPAN, S., KRAUS, V. B., KROGER, B., MÜNGER, K., HOWLEY, P. M., PHELPS, W. C. ET AL., "Adenovirus EtA, Simian Virus 40 Tumor Antigen, Human Papillomavirus E7 Protein Share the Capacity to Disrupt the Interaction between Transcription Factor E2F and the Retinoblastoma Gene Product," *Proceedings of the National Academy of Sciences of the United States of America*, v. 89, n. 10, (1992), pp. 4549-4553.

⁴⁹ See HALBERT, C. L., DEMERS, G. W. and GALLOWAY, D. A., "The E7 Gene of Human Papillomavirus Type 16 Is Sufficient for Immortalization of Human Epithelial Cells," *Journal of Virology*, v. 65, n. 1, (1991), pp. 473-478.

⁵⁰ HURLIN, P. J., KAUR, P., SMITH, P. P., PEREZ-REYES, N., BLANTON, R. A. and McDUGALL, J. K., "Progression of Human Papillomavirus Type 18-Immortalized Human Keratinocytes to a Malignant Phenotype," *Proceedings of the National Academy of Sciences of the United States of America*, v. 88, n. 2, (1991), pp. 570-574.

In summary, following prolonged investigation of HPV, particularly focusing on the technical difficulties of detecting the virus or growing it in culture, a strong statistical-mechanical link with cervical cancer was uncovered, with epidemiological investigations playing a subordinate role.⁵¹ It is now thought that the evidence linking HSV and cancer of the uterine cervix can be explained on the grounds of similarity of risk factors: behaviours which place the individual at high risk for contracting HPV also place them at high risk of contracting HSV.

4. CAUSAL CLASSIFICATION AND CONCEPTUAL CHANGE

At the outset of this piece I suggested that the discovery of the viral oncogenesis led to a revisionary, branch-jumping reclassification of cancer aetiology in general. While I hope I have demonstrated how this came about, what is the significance of such a reclassification? In order to answer this question, I need to discuss the ways by which disease are classified in clinical practice.

For instance, when making a diagnosis, the clinician may use classifications in order to understand the nature and cause of symptoms. Two sorts of classification are particularly important for physical illnesses. One way of classifying a disease process would be to begin by dividing possible causes of disease by their relevant anatomical site. To give an example, the symptom “pain in the abdomen” may arise as a result of disease occurring in a number of sites. These include:⁵²

1. The stomach or duodenum (for instance, a perforated gastric or duodenal ulcer, perforated gastric carcinoma or acute gastritis),
2. The intestines (small bowel obstruction, Crohn’s disease, intussusception),
3. The appendix (acute appendicitis),
4. The pancreas (acute pancreatitis, pancreatic trauma),
5. The gallbladder or bile-ducts (gall stone, acute cholecystitis, acute cholangitis),
6. The liver (trauma, acute hepatitis, malignancy, congestive heart failure); or
7. The spleen (trauma, spontaneous rupture, infarction),

and so on. But we could also classify these diseases in a second way, by their aetiology.⁵³ So the same symptom might be caused by:

1. Vascular diseases (congestive heart failure causing hepatic engorgement, splenic infarction...),
2. Infections (acute hepatitis, spontaneous splenic rupture),⁵⁴
3. Cancer (perforated gastric carcinoma, small bowel obstruction, hepatic malignancy),
4. Trauma (pancreatic trauma, hepatic trauma, splenic trauma),

⁵¹ Cf. ZUR HAUSEN, H., “Papillomavirus in Anogenital Cancer: The Dilemma of Epidemiologic Approaches,” *Journal of the National Cancer Institute*, v. 81, n. 22, (1989), pp. 1680-1682.

⁵² These causal categories are what I refer to when I suggest that viral oncogenesis caused a branch-jumping event. In this instance, both the disease causes and classificatory categories are derived from BOUCHIER, I. A. D., ELLIS, H. and FLEMING, P. R. (eds.), *French’s Index of Differential Diagnosis*, 13th ed., Arnold, London, 1996.

⁵³ Aetiological classifications (informally known as *surgical sieves*) such as this, are widely used in clinical practice. Sadly little is written about such classifications in the academic literature.

⁵⁴ Spontaneous splenic rupture is generally a consequence of infectious mononucleosis.

5. Autoimmune diseases (Crohn's disease),
6. Metabolic diseases (gall stone),
7. Endocrine diseases,
8. Degenerative diseases,
9. Iatrogenic and idiopathic diseases,
10. Congenital diseases.

These causal classifications are useful, in a relatively superficial sense, for understanding patterns of disease. As an example, if we classify a set of diseases anatomically it may be difficult to detect their underlying aetiology. So while an individual might have symptoms compatible with pain arising in the pancreas, liver and spleen, an anatomical classification merely suggests an appropriate group of sites suitable for further investigation. If we were to attempt an aetiological classification, on the other hand, the same individual might be seen to have suffered trauma to the pancreas, liver and spleen, suggesting a coherent mechanism underlying all of their ailments. While in such a simple case any cognitive gain seems trivial, in more complex disease process aetiological classifications are likely to be rather more helpful. Take the case of an individual with an enlarged thyroid gland, an irregular heart rhythm (an arrhythmia) and acute abdominal pain. Here, an aetiological classification is likely to suggest an underlying mechanism in a way that an anatomical classification will not.

In this instance, one possible explanation for these symptoms could be as follows. First, the enlarged thyroid gland could indicate that the patient is suffering from Graves' disease. One consequence of this is a predisposition towards atrial fibrillation, a type of cardiac arrhythmia. A consequence of this atrial fibrillation is an increased risk of unwanted blood clots. One of these clots may have caused a splenic infarction, leading to the abdominal pain. In this case, an anatomical classification will have been unhelpful in discovering this causal mechanism. Importantly for practice, discovering this underlying disease mechanism suggests therapeutic strategies in a manner that anatomical classification does not.

There is a more fundamental sense in which reclassifications are important. The further discovery of viral causes of cancer, such as has recently happened in the case of Merkel cell carcinoma, or the discovery of new treatments for existing cancers requires the exploitation of causes in such a way as to be impossible in the absence of a correct classification.⁵⁵ It would have been inconceivable for this to have occurred if the discovery of viral oncogenesis had constituted a conceptual change taking the form of simple addition to cancer as it existed within the degenerative disease hierarchy. These causal arguments would remain unintelligible without acceptance of such revisions in conceptual structure. In part, the reasons for the acceptance of this reclassification relate to the improvements offered in terms of causal explanatory coherence. Maximising coherence involves retaining much evidence that was developed at earlier stages of understanding cancer causation. For example, in order to maintain explanatory coherence, we should seek to retain the finding that cervical cancer incidence varies by number of sexual partners. This has occurred by fitting this observation into the broader framework of causation by HPV. Now promiscuity does not cause cervical cancer. Instead, it increases the risk of

⁵⁵ Cf. KASSEM, A., SCHOPFLIN, A., DIAZ, C., WEYERS, W., STICKELER, E., WERNER, M. ET AL., "Frequent Detection of Merkel Cell Polyomavirus in Human Merkel Cell Carcinomas and Identification of a Unique Deletion in the VP1 Gene," *Cancer Research*, v. 68, n. 13, (2008), pp. 5009-5013.

contracting HPV. Thus the discovery of viral oncogenesis does not involve replacing all that had been known about cancers. Rather, it was in part a matter of fitting existing evidence in to a new causal archetype.

This is reflected in the sorts of tools for causal inference applied to the case. For instance, within the paradigm of infectious disease, there were already well-used tools for interpreting epidemiologic and laboratory data, such as the Koch-Henle postulates which could be used to interpret existing data when making new causal claims.⁵⁶ So when an infectious cause was suspected for cervical cancer, researchers began to use tools originating in infectious disease research, such as seroepidemiological surveys, electron microscopy and animal transfection experiments in their search for causes. This — ideally — allowed the interpretation of risk factors and other pieces of causal knowledge identified at an earlier stage of cancer classification. Thus the risk of developing the disease under certain conditions of marital status, sexual habits, social class and so on were examined in terms of a particular underlying causes, namely a virus. While it was the discovery of viral oncogenesis that finally made the case for cancer reclassification, it was the suspicion that a conceptual reclassification could be made that allowed these questions to be formulated in the first instance.

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⁵⁶ CARTER, K. C., *The Rise of Causal Concepts of Disease: Case Histories*, Ashgate, Hants, 2003.

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CONCEPTUAL REVOLUTIONS IN INFORMATION SCIENCE: THE CASE OF WEB¹

María G. Bonome

In the context of conceptual revolutions, this paper analyzes web as a key matter for information science. Web is an artificial space where a set of processes related to information take place. These processes are representation, storage, processing, and information retrieval, and all of them are oriented to decision making. So aims, processes, and results take part on them: web contents tend to be put together and be connected according to the organization or kind of decision making they support.

It is a task with historicity and oriented to aims: web is continually changing to get a more efficient structure. This leads web to pay attention to norms and standards that make possible to share information in an easier and faster way. In these circumstances, two characteristic features of applied sciences appear: there is prediction about possible aims, and there is prescription to try to regulate contents and the use of information that pursue to solve specific problems.

This approach about *web* from the perspective of information requires considering two points of view: a) web as means or format that enable to communicate information to its users in an understandable way, and b) web as informative content itself. In my judgment, this distinction is important, because the content is sometimes confused with the means. This happens to *web* users (they tend to confuse the interface with the system) and to web makers not very specialized. To make web possible, different scientific fields related to artificial issues have had to take part: design oriented to solve specific problems. In general, there are two fields that make possible the existence of web: the scientific and the technological ones, where the first one is dual — as we will see —.

1. A REVOLUTION IN THE FIELD OF THE ARTIFICIAL RELATED TO INFORMATION

During the last two decades we have attend a “revolution” related to the use of concepts. It has been in the field of representation and processing of information by computational means.² The spectacular change has emerged as the junction of several factors — inner and outer — around the development of the internet. Here it is a linkage between two sciences of design — *computer sciences* and *information science* —, and communication and information technology. Also the

¹ This research is supported by the Spanish Ministry of Science and Innovation (FFI2008-05948). The research project is focused on “The Sciences of Design as Sciences of Complexity.”

² We use to talk about “design” of information, but it might be more proper to talk about “representation” of information. In this sense, Jef Raskin points out that the design of information “is a misnomer. Information cannot be designed; what can be designed are the modes of transfer and the representations of information... it is important for designers to keep the concepts of information and meaning distinct,” RASKIN, J., “Presenting Information,” in JACOBSON, R. (ed.), *Information Design*, The MIT Press, Cambridge, MA, 1999, p. 342.

users of web have a key role together with the social pressure for advances about the spreading of information.

The internet is a means for the exchange of information. As a lot of people have access to the internet, it enables them to have access to informative contents. The internet has contributed to shape a new reality other than physical objects or different from the world of formal logic and mathematics, even though it has a relation to them. Through the use of internet we have attended some changes in the way people perceive some elements related to space and time — the physical environment — while there have been some changes in the social environment — human relationships —, and in the artificial component itself that makes possible such changes.

By means of an innovative technological medium — the more and more sophisticated computers — “symbolic processing” has been brought off. In this way, the sequenced signs in programs have enable the flow and interrelation of ideas, beliefs, experiences, memories and images, together with artistic interpretations of all kind. All of them shape the digital construction of a “synthetic world.”³ It is about a *virtual reality* that has an entity other than the characteristic one of the natural reality and different from the social world. Scientific research tasks have traditionally been concerned with natural and social worlds. So, talking about conceptual revolutions with scientific and technological components implies talking about the net called the *World Wide Web*.

Ontologically, the web belongs to the realm of the artificial, in the sense that it is something build by human being (human made) and it is opposed to what is given in the nature.⁴ It is in relation to the sciences of the artificial, and that is a field related to designs made to increase human potential abilities. This means that it deals with artefacts that help human beings to adapt to the environment where they develop their lives. These sciences of design are different from the sciences of the nature and also from the social sciences.⁵

Specifically, the realm of the representation and processing of information by computational means is related to two sciences of design: computing (*computer sciences*) and documentation (*information science*). Each of these sciences of design has aims, processes, and results that are linked in the case we know as World Wide Web.

The implicit capacities of these two sciences of design mentioned above are improved with the support of communication and information technologies. Besides, there is a social aspect: all kind of institutions use it, so communication and information technologies play a key role in modern societies. In this sense, communication through web brings about changes in the way human interaction is understood. And this has social consequences in two opposite directions: on the one hand, communication through this net enables to get together remote people in an interactive way; and, on the other hand, it brings about certain isolation — a kind of “individualist atomism” — in the sense that people interact with a machine instead of interact with other

³ Cf. FLORIDI, L., *Philosophy and Computing. An Introduction*, Routledge, London, 1999, p. 8.

⁴ About the features of the artificial, see SIMON, H. A., *The Sciences of the Artificial*, 3rd ed., The MIT Press, Cambridge, MA, 1996.

⁵ Cf. GONZALEZ, W. J., “Configuración de las Ciencias de Diseño como Ciencias de lo Artificial: Papel de la Inteligencia Artificial y de la racionalidad limitada,” in GONZALEZ, W. J. (ed.), *Las Ciencias de Diseño. Racionalidad limitada, predicción y prescripción*, Netbiblo, A Coruña, 2007, p. 43.

people.⁶ These factors are connected with information management, a later phase to design in the realm or the artificial.

Through information management by means of web the relation with public administration takes place through *e-government*, learning can be done on line (*e-learning*), business on line (*e-business*), etc. This social aspect is not only from the individual with respect to the corresponding social entity but the interchange of information happens also into the organizations. This is the case of corporative intranets that leads to the own origin of the web into a scientific-technological entity like CERN.

2. A SCIENTIFIC-TECHNOLOGICAL TASK: THE INTERDISCIPLINARY CONTRIBUTION

The conceptual revolution introduced by web is related to information accessibility, the capacity of information retrieval, the interactive interchange of information, etc. At the same time, all these tasks can be seen from the point of view of the content — the conceptual content itself —, and the users perspective that ask for new advances in the pointed out levels: accessibility, retrieval capacity, interactivity, etc. This second point of view involves a set of contextual elements, such as a social component, an economic factor or an ingredient of the cultural change.

Every of these aspects (conceptual content, users demands, contextual elements) can receive scientific study. Firstly, the two initial ingredients of web attract attention: a) the processes that enable to elaborate informative resources (the conceptual content), and b) the way they are presented to their potential users (the attention to users). In the first case, unlike the traditional documental products, web contributes to give an economic value to informative resources. Then, information comes into an economic context, like another market product. In relation to the second ingredient — the way of presentation —, not only web provides information accessibility to users, but also it makes possible that information can turn into knowledge.⁷

Firstly, web is a platform that enables information storage (or knowledge storage) and, secondly, it makes possible that this conceptual content can flow and be shared. As Herbert Simon insisted, one of the key elements in decision making and problem solving is the capacity of computing information.⁸ In this sense, both web and the computers that lean its existence — the technological medium — bring about a double function: the access to a bigger volume of information and the widening of the capacity of calculation of users to make decisions or solve problems.

Here it appears an ambiguous use or the word “web:” sometimes is used as a synonym of the *Internet* (the net where information flows). Sometimes it refers to *web sites*, the places that are identified through mechanisms like URL (*uniform resource locator*) in a singular way and that

⁶ About internet culture see COOPER, W., “Internet Culture,” in FLORIDI, L. (ed.), *Philosophy of Computing and Information*, Blackwell, Oxford, 2004, pp. 92-105.

⁷ This means that there are three consecutive cognitive levels: data, information and knowledge. The last one adds to information a categorization or systematization in a way that contributes to articulate information.

⁸ Human beings are rationality bounded especially about information: a) the capacity for information storage is bounded; and b) the capacity for information processing is also bounded, both to consider all the information that is relevant for a matter at a time, and our capacity of calculation to consider all the possible alternatives. Cf. SIMON, H. A., “La racionalidad limitada en Ciencias Sociales: Hoy y mañana,” in GONZALEZ, W. J. (ed.), *Racionalidad, historicidad y predicción en Herbert A. Simon*, Netbiblo, A Coruña, 2003, p. 97.

refer to a specific subject or organization. Finally, it mentions every hiperdocument or *page* that corresponds to a file into a web site.

The term *web*, as it is used here, corresponds to a divided space of information that is different from the others that are in the Internet. But computers are related to these three uses mentioned. They also affect in decision making. They do it through their instrumental task of computing because they go beyond the normal bounds of people. The link between the system and the person who uses it is an interface where contents are organized into a structure that is usually called “web.”

2.1. From the Scientific to Technological Realm

To make possible that the web has become real, some different levels intervene in its design: on the one hand the scientific realm, and, on the other hand the technological one. Within the *scientific* realm we can distinguish two aspects: 1) the contribution of *computer sciences*, the ones oriented to develop systems, programs or languages to represent or process information automatically; and 2) the contribution of documentation (or *information science*) whose main task is informative contents management.⁹

The innovations of material instruments that enable the flow of information systems are within the technological realm. They are *the hardware* or physical part of communication and information technologies. The technological possibilities together with some scientific concepts — computational and documentary — have enabled to carry out an automatic description and control of information. In this way, codified documents have been made and their contents are now available to a lot of people.

Within the scientific disciplines of the first kind, that is, the ones devoted to computational tasks, Paul Thagard point out three approaches: i) the develop of cognitive modelling, ii) the engineering of artificial intelligence, and iii) the theory of computation.¹⁰ The aim of the first one, the construction of *cognitive models*, is to simulate aspects of human thinking. It does it through an interdisciplinary study of mind. So it considers the contributions of philosophy, psychology, artificial intelligence, neuroscience, linguistics or anthropology.

The *engineering of artificial intelligence* — the second approach — do research about what are the differences between computers and human beings. Its task is to get that computers perform the tasks of search, analysis and information retrieval that human beings find difficult to perform.¹¹ To reach this aim, AI formulates algorithms that search to represent and process complex tasks related to information. The third approach of computational sciences is *theory*

⁹ *Information science* is the name given to the field that contents “documentation.” On the one hand, it can be understood in a broad sense, that is, it covers the set of disciplines that work in archives, libraries and documentation centres; and, on the other hand, in a narrower sense, it refers to specific informative processes such as information creation, purchase, organization, evaluation, storage, transmission, retrieval and spreading. Cf. BEREJO, A., “Caracteres de la predicción en las Ciencias de la Documentación: de la *Information Science* al Análisis Documental,” in GONZALEZ, W. J. (ed.), *Las Ciencias de Diseño: Racionalidad limitada, predicción y prescripción*, p. 217.

¹⁰ Cf. THAGARD, P., “Computing in the Philosophy of Science,” in FLORIDI, L. (ed.), *Philosophy of Computing and Information*, pp. 307-308.

¹¹ About human intelligence and the design of artificial intelligence, see GONZALEZ, W. J., “Configuración de las Ciencias de Diseño como Ciencias de lo Artificial: Papel de la Inteligencia Artificial y de la racionalidad limitada,” pp. 61-63.

of computation, its aim is to do abstract mathematical analysis that enable to infer laws from numerical data (for instance, to evaluate hypothesis).

Computing sciences contribute with key elements to web building. They do it through automated systems, and that is a condition for web to get its informative aim. But here the sciences that work in content organizing and content management make a contribution too. So there is a dual approach: on the one hand, information has to be represented in a programming language, storage in a data base and in condition to be reached by web crawlers; but, on the other hand, the design has to be prepared to show information in an understandable way when a user ask for it. Without content management the system can be said not to work to face the aim it has been conceived.

Then, available information must have an organized structure and this task corresponds to information science. This structure is necessary because of the increasing of information volume and the increasing of information complexity that is available. The amount of this more and more complex information has caused a new problem: information overload. Because, due to bounded rationality in human being, people are not able to classify and process the huge amount of information we have access through the World Wide Web or through corporative intranets.

In other words, the aim of web is not merely to contain and transmit data. It should also show that it contains the information in a coherent way and it communicates the information in an efficient way to potential users. Because of this, a fundamental requirement for web designing is understand the structure of the information so that the organization of the information becomes knowledge. Here the concept of “metainformation” appears and make easier to do the search through the thousand or hundred thousands of pages there are in a web site.¹² It is precisely here where information science has a key role: to make the scientification of informative content management.¹³

2.2. *The Role of Web in Information Science*

Information science has been usually taken charge of studying some processes related to information: identification, evaluation, description, classification and codifying of information. All these tasks are aimed to information retrieval in any kind of possible document. This derives from the scientific features of information science: a) this science has a characteristic language, which is different than the one used in other disciplines; b) it is articulated in theories oriented to solve specific problems; c) it applies a specific knowledge that is different from other disciplines, and in addition it enables to articulate contents of other disciplines; d) its method is oriented to solve practical problems in an environment of archives, libraries and documentation centres; e) this science is entitatively a social human activity; f) it is associated to a set of values, both inner (exhaustivity, accuracy, consistency, simplicity, easily to use, versatility) and outer (public service, cultural vehicle, etc.); and g) this science might be evaluated ethically, both from an internal level (reliability, honesty, etc.) and an external level (avoid prejudices to users, etc.).¹⁴

¹² Cf. MAZUR, B., “Information Design in Motion,” in ALBERS, M. J. and MAZUR, B. (eds.), *Content and Complexity*, Lawrence Earlbaum, Mahwah, NJ, 2003, p. 25.

¹³ As it is known, Ilkka Niiniluoto calls scientification to the process through what a professional practice turns to be genuine scientific knowledge in the context of applied sciences of design. Cf. NIINILUOTO, I., “The Aim and Structure of Applied Research,” *Erkenntnis*, v. 38, (1993), p. 9.

¹⁴ Cf. BEREJO, A., “Caracteres de la predicción en las Ciencias de la Documentación: de la *Information Science* al Análisis Documental,” pp. 218-219.

But these features have been subject to changes in the sense that they deal with documental processes. This historicity can be noticeable in the case of web, because documental knowledge has to be mixed with knowledge about computer languages and software that hold digital products in the context of web. From the point of view of analysis, the narrow interaction between documental and computational realms sometimes brings about a confuse definition of some design tasks.

From the point of view of content configuration, building a web need to consider other disciplines and thematic realms besides information science. They are information design, information architecture, and the studies about usability¹⁵ and accessibility.¹⁶ Some of these disciplinary fields have arisen from the mix of knowledge of some traditional disciplines. On the other hand, other disciplines just have to adapt their methodology to advance with respect to some products that had a different configuration only a few time ago.

Related to information complexity a thematic specialization has happened to deal with web. In 1975, even before web existing, the expression “information architecture” was coined. It pursues to make the complex clear, that is, to make the information understandable for other human beings. That is the reason why Richard S. Wurman has characterized it like the study of information organization whose aims are to allow the users web surfing to find information and help them to understand knowledge.¹⁷

The main tasks of the architecture or information in web design have been pointed out by Louis Rosenfeld and Peter Morville. In their book *Information Architecture for the World Wide Web*, they indicate the following duties: 1) to set and make clear the mission and view or the web site; 2) to set its informative content and the technological functionalities that it has to content and offer; 3) to define and specify the shape and means through what the user can find and have access to information; and 4) to define the means and channels for the future growing and development of the web site.¹⁸

Through an analogy with building architecture, it could be said that the information architecture is the responsible for designing and constructing the building and its components, its halls, its open and service areas. But now the building is digital, and its components are the informative contents. The inner space is made through the organization of contents, and with the systems for surfing, browsing, accessing and labelling information.

To develop his or her work, an architect of information has to have knowledge about the epistemic factors and the methodological aspects of information science. He or she has to deal with metadata, controlled vocabularies, information retrieval, classification systems, cataloguing, user studies, etc. But, besides he or she has to know the operation of computational elements, and the software products related to web site design. These includes labelling languages, labelling systems for contents, surfing and browsing systems, information retrieval systems, etc.

¹⁵ About usability contributions, QUESENBERRY, W., “Five Dimensions of Usability,” in ALBERS, M. J. and MAZUR, B. (eds.), *Content and Complexity*, Lawrence Earlbaum, Mahwah, NJ, 2003, pp. 81-102.

¹⁶ In this context, accessibility means the level of access that people have to web content. The World Wide Web Consortium (W3C) has developed some recommendations — Web Accessibility Initiative — to set some principles to guarantee this access.

¹⁷ Cf. WURMAN, R. S., *Information Anxiety 2*, Que, Indianapolis, IN, 2000, p. 23.

¹⁸ Cf. MORVILLE, P. and ROSENFELD, L., *Information Architecture for the World Wide Web*, O’Reilly, Sebastopol, CA, 1998, p. 11. There is a third edition of this book in 2006.

“Information design” includes a wide range of tasks. Among them there are the traditional ones of visual design, human factors, and technical communication.¹⁹ The multidisciplinary origin of the knowledge it uses causes the difficulty to give a proper characterization of the discipline. The concepts information design uses come from some human and social disciplines like social anthropology, cognitive psychology, linguistics, organizational psychology, rhetoric, etc. There are concepts of technological knowledge too like instructive and technological architecture. Besides, practical and operative knowledge of graphic design intervenes as well as instructive typographical design or usability.²⁰ But, this difficulty for a proper characterization comes from a significant change too, due to the introduction of web as virtual channel because this means to introduce new theoretical knowledge for the design of its professional work.

Although the frontier between “information architecture” and “information design” could seem vague, because they have to share both knowledge and practical skills, a different approach can be established. In this sense, J. J. Garrett maintains the following: “information architecture and information design are indeed quite different... Information architecture is primarily about *cognition*... Information design is primarily about *perception*... Information architecture belongs to the realm of the abstract, concerning itself more with structures in the mind than the structures on the page or screen. Information design... couldn't be more concrete, with considerations such as colour and shape fundamental to the information designer's process.”²¹

So, the development of these thematic realms gives an idea of the complexity about web. And it can be specially seen when the elements that have been pointed out are seen from the perspective of content management, the point of view where the role of contents is outstanding. In this sense, a proper configuration of web has to consider all of the multiple factors that intervene on it, that is, in the organization of a space with conceptual components where human beings interact. The fact that web navigation was “intuitive” or “complex” — using the same technological means — depends on how information has been organized.

3. WEB IN INFORMATION SCIENCE AS SCIENCE OF DESIGN

To understand the scientific approach that makes possible the organization of contents into a website, it is interesting to analyse the contribution of Herbert Simon about sciences of design and apply it to the participation of information science to web design. To this author, “sciences of design” are scientific realms whose main task is to make easier the adaptation of people to their environment, so design is *human-made* and is aimed to get deliberately searched aims.²² Within this approach, these sciences are a subgroup into the sciences of the artificial, because there are other studies about the artificial (like, for instance, the sciences of the materials).

For Simon, the sciences of the artificial — and specifically the sciences of design — are empirical disciplines. Together with the test through empirical methods, they share the notion of *model* with the sciences of the nature and social sciences: all of them converge in the meaning of “model” like “representation” or “resemblance” of the real. Nevertheless, they differ with the

¹⁹ Cf. ALBERS, M. J., “Introduction,” in ALBERS, M. J. and MAZUR, B. (eds.), *Content and Complexity*, p. 4.

²⁰ Cf. REDISH, J., “What is Information Design,” *Technical Communication*, v. 47, n. 2, (1999), pp. 167-168.

²¹ The differences between information design and information architecture are in GARRETT, J. J., Reply in “What's in a Name?,” *Design Matters*, v. 5, n. 2, (2001), p. 3.

²² Cf. SIMON, H. A., *The Sciences of the Artificial*, pp. 111-138 and 164.

sciences of design in their aims, processes and results. This is because they research on objects with a different ontological character, which in this case are artificial.²³

From a philosophic-methodological point of view, Wenceslao J. Gonzalez points out a list of features that help to understand the scientific dimension of design. i) “Within the present context, design has genuine features of ‘science’ (language, structure, knowledge, etc.), so it can be distinguished from the professional practice of designing and it can also differ from the typical endeavour of ‘industrial design’ (or, in general, it is different from ‘technological design’); ii) scientific design is studied by philosophy and methodology of science: it appears within ‘the sciences of the artificial,’ so its thematic sphere is different from the sciences of the nature and different from the social sciences; iii) every ‘scientific design’ is part of a human activity where there are aims, processes and results (the design is aimed to solve specific problems by means of well defined processes); and iv) the existence of these consecutive steps — aims, processes, and results — involves some factors regarding scientific design, among which we can find the use of rationality (of means, and of ends), the use of predictions, and the stipulation of prescriptions to achieve the selected goals.”²⁴

In the case of information science it can be seen than design has an important human and social aspect. Because of this, these design discipline can be included in the realm of social sciences simultaneously with the realm of sciences of the artificial. This is like that because in information science “its origin, development and consequences have place in a social environment.”²⁵

The fact of design itself — gathering information —,²⁶ understand as a scientific task of design, has to be oriented to three consecutive levels: a) the search aims; b) the selection of the most adequate processes; and c) the criteria to apply to the evaluation of the results.²⁷ This triple consideration — aims, processes, and results — is separately applicable to design in each of the fields that intervene in the configuration of web.

On the one hand, computer sciences have a scientific task where objectives are searched, computer processing that are considered the most plausible to get that aims are selected, and finally, the obtained results are analyzed. This analysis is made to check how much such methods have contributed to reach the searched goals. And, on the other hand, within information science there is a triple structure oriented to aims too, since information management solve problems according to aims, processes and results.

Nevertheless, even though every of these aspects has a separately development, there is a clear interaction that give raise to some common aims and make possible to work on the

²³ Cf. GONZALEZ, W. J., “Configuración de las Ciencias de Diseño como Ciencias de lo Artificial: Papel de la Inteligencia Artificial y de la racionalidad limitada,” p. 45.

²⁴ GONZALEZ, W. J., “Análisis de las Ciencias de Diseño desde la racionalidad limitada, la predicción y la prescripción,” in GONZALEZ, W. J. (ed.), *Las Ciencias de Diseño. Racionalidad limitada, predicción y prescripción*, p. 4.

²⁵ GONZALEZ, W. J., “Análisis de las Ciencias de Diseño desde la racionalidad limitada, la predicción y la prescripción,” p. 6.

²⁶ Cf. SIMON, H. A., “Problem Forming, Problem Finding, and Problem Solving in Design,” in COLLEN, A. and GASPARSKI, W. W. (eds.), *Design in Systems: General Applications of Methodology*, vol. 3, Transaction Publishers, New Brunswick, NJ, 1995, pp. 245-257. Spanish translation by Pablo Vara and Wenceslao J. Gonzalez: “Formación de problemas, detección de problemas y solución de problemas en Diseño,” in GONZALEZ, W. J. (ed.), *Las Ciencias de Diseño: Racionalidad limitada, predicción y prescripción*, pp. 149-159.

²⁷ Cf. GONZALEZ, W. J., “Análisis de las Ciencias de Diseño desde la racionalidad limitada, la predicción y la prescripción,” pp. 5-6

whole in the selection of proper methods. The distinction among the different thematic fields is perhaps easier to see in the analysis of results, in epistemological and methodological terms. When the goals that have been reached are examined in relation to the goals set out at the beginning, it is easier to identify which field is the responsible for fails and specify what questions can be improved.

From this characterization of web as an artificial element, we can insist on the contributions of information science to content management. In this sense, a series of elements about aims, processes and results can be mentioned.

3.1. Design of Aims

The moment when the aims are established is very important as a consequence of the teleological dimension of the artificial. It is the first step — and one of the most decisive — for *web* design in relation to contents. At the beginning of the process, the searched aims are going to shape and define the resulting design, although there could be variations during its development. And in this task not only epistemic or cognitive values intervene, but economic and other kind of values has an influence.²⁸

To establish the aims of the design the role of individual agents is central. The users of the documental product that is the *web* have a fundamental task. This approach has been increasing to the point that a change is taking place in the consideration of the final aims in the designs. In fact, the searched aim with the representation, processing, and information retrieval through the *web* used to be supply relevant information to users. It consisted in give information in the moment where it was required to enable a high quality decision making.

From this point of view, the aim of web design is to give information to users. Although a change in the orientation is recently considered: it is no only get *information* as a product of web but also get *knowledge*. In other words, the conceptual content expressed through the web has to enable the users to get “knowledge” as a result of their interaction with the system through the interface. This is highlight with the increasing importance of usability studies.

This means that “knowledge generation” takes place, understood as the *cognitive capacity* of individuals to assimilate new information and add it to the previous knowledge they had. In that case, web design consists not only in making information accessible but also causing its assimilation into the cognitive system of individuals. This complex task is only possible through the contribution of contents of several disciplines mentioned before, combined with information science. Therefore it could be said that the aims in web design has to pay attention to the necessities in three levels: the content — the cognitive —, the context — that is social and historical — and the users. This could be translated in: a) tasks about content architecture, b) information design, and c) interaction design.

3.2. Selection of Processes

Obviously, within the three components of web configuration as teleological activity — aims, processes and results —, the second element is where a more intensive interaction takes

²⁸ Cf. GONZALEZ, W. J., “Economic Values in the Configuration of Science,” in AGAZZI, E., ECHEVERRÍA, J. and GÓMEZ, A. (eds.), *Epistemology and the Social*, Poznan Studies in the Philosophy of the Sciences and the Humanities, Rodopi, Amsterdam, 2008, pp. 93-96.

place. Indeed, it is in the processes where a closer collaboration or dependence of the different thematic variables that act in web design takes place: the computational, the organizational and the technological. The processes used to advance in getting the established aims consist on the combination of the sciences of design with the communication and information technologies.

From the point of view of the information science, the processes that concern to web are those that lead to identify, analyze and classify information in such a way that make possible its retrieval. There are several methodological processes in action that have to be selected depending on the searched aims and the available means. Some of these processes have been done manually by professionals of information science and some of them are still done in the same way.²⁹ But those tasks that can be represented through series of signs without a qualitative analysis are carried out by automatic means for some time ago.

Although such processes of information processing are made by computational means, the design of *software* products go beyond the field of computer sciences: it requires applying schemes elaborated by information science, that is, it needs the methodological component of knowledge management. This is highlighted in cases such as automatic indexing that enables to know the terms contained in a document which are relevant to answer to a web search, or the way of identifying every hypertext document including metadata.³⁰

3.3. Evaluation of Results

As in any kind of evaluation, it is possible to insist more in the inner component or to value more the outer incidence. In the first case, the capacity to solve problems (when it is an applied science) or the efficacy in the transformation of the real (when it is technology) is valued. And, in the second case, the things that the social or cultural environment — the users — perceive as more adequate to their interest, preferences or needs are more appreciated.

Related to the results of web it is clear that the two kinds of evaluations are possible: the inner and the outer, and they are not blocked components. Besides, there is a factor of historicity: the own singularity of web design determines that they can be in a continuous revision and re-elaboration. Web has an extraordinary dynamism: in certain sense, *web* is a living space — its contents are subject to a constant actualization —. This reinforces the need of a continuous evaluation.

As in any process of design, in web design there are some restrictions from the first moment. Some of them come as a given from the aims or goals that are in the origin of the design. But, besides, there can be other kind of limitations, specially the ones that come from the environment. The process of design can be understood as the generation of alternatives from the information and knowledge available and the subsequent election among them. In that way, at the same time that alternatives are being generated some are elected and some are rejected. From this interweaved generation and election process the option finally selected will come up.³¹ So the

²⁹ This is the case, for instance, of cataloguing. Although some authors talk about “automatic cataloguing” it actually doesn’t exist. Deciding what is the bibliographic description of a documental resource is something not possible to do by computational means by now. Some other tasks that required a high quality work are still manually made.

³⁰ Metadata are data informing about shape and content of every hipertextual document included in a web site. They are represented in specific languages and its aim is to facilitate the search engines to localize and index documents.

³¹ Cf. SIMON, H. A., “Problem Forming, Problem Finding, and Problem Solving in Design,” p. 247.

problem of complexity appears again: it is really complex to consider and weigh up the huge amount of considerations that come into play here.³²

This involves that some flexibility to enable adaptation to new circumstances is needed. The revision makes possible that at any moment of the process new knowledge responding to new criteria could be introduced, and modify aims or introduce new restrictions if necessary could be possible too. It has to be taken into consideration that when a project for web building is made it is not considered as a finished product, but it has to consider the future projection. This prospective approach is a factor of progress of web: the advances or modifications both in the informative content and in the technological means used. In both cases there is a future projection.

4. PREDICTION, PRESCRIPTION, AND VALUES IN WEB

Within this orientation to future, web is a scientific product that need consider to whom is the design aimed. This environmental element is heterogeneous, because it refers to the set of people who have access to Internet. The complexity is evident: together with the multiple interests that move people it could be added the uncertainty about the results of their interaction.

In this sense, besides the interests of the individual agents there is a multiplicity of interests in the different social, cultural, economical, political or whatever kind of group. In that case, the contents of the web are *elaborated by* groups more or less homogeneous or are directed not to unstructured groups.³³ At first, people from all over the world have access to the contents but only those who are interested on them will use them.

Within this orientation to future that involves a practical application in solving specific problems (in this case informative ones) it could be asserted that web is inscribed within the applied sciences of design. This is like that because both *information science* and *computer sciences* could be considered applied sciences of design. These two sciences of the artificial have a scientific development in search of new knowledge oriented to the applied field: they have the task of solving a specific problem and increasing the efficiency in its solution.³⁴

This consideration of information science as applied sciences of design can be observed from a series of features they have: ‘i) they are at present ‘sciences’ within an artificial domain and no simply ‘techniques’ (gained practical knowledge); ii) they are ‘applied’ because they are oriented to solve specific problems within a bounded environment; and iii) they are ‘of design’ because they start from an artificial construction — a design — that modulates the aims, the processes and the results of information in the realm of archives, libraries and documentation centres.’³⁵ Web site building is included here.

³² This subject is developed in SIMON, H. A., “Designing Organizations for an Information-rich World,” in GREENBERGER, M. (ed.), *Computers, Communications, and the Public Interest*, The Johns Hopkins Press, Baltimore, MD, 1971, pp. 37-72. Reprinted in SIMON, H. A., *Models of Bounded Rationality*. Vol. 2: *Behavioral Economics and Business Organization*, The MIT Press, Cambridge, MA, 1982, pp. 171-185.

³³ This corresponds to a Simon’s idea: to face up the problem of complexity, it is necessary some kind of inner articulation or hierarchy, in other way it is very difficult to get to cover on the whole Cf. SIMON, H. A., “Science Seeks Parsimony, not Simplicity: Searching for Pattern in Phenomena,” in ZELLNER, A., KEUZENKAMP, H. A. and McALEER, M. (eds.), *Simplicity, Inference and Modelling. Keeping it Sophisticatedly Simple*, Cambridge University Press, Cambridge, 2001, pp. 32-72. Spanish translation by Pablo Vara and Wenceslao J. Gonzalez: “La Ciencia busca sobriedad, no simplicidad: La búsqueda de pautas en los fenómenos,” in GONZALEZ, W. J. (ed.), *Las Ciencias de Diseño: Racionalidad limitada, predicción y prescripción*, pp. 71-107.

³⁴ Cf. NIINILUOTO, I., “The Aim and Structure of Applied Research,” p. 5

³⁵ BEREJO, A., “Caracteres de la predicción en las Ciencias de la Documentación: de la *Information Science* al Análisis Documental,” p. 224.

Through the scientific approach, design looks at problem solving in this case related to information. At the same time, scientific design takes part as a constitutive part of technological design. In this case, the contributions of information science together with computer sciences insist in the technological knowledge of the communication and information technologies. Within the technological design the aim is to transform the existing reality. Scientific prediction related to a possible future serves as a basis to “design the future.” But prescription is required, the knowledge to be able to act: it is necessary to give action guidelines to solve the problems about the future that are raised.³⁶ Web design can not consider only elaborate alternatives to choose: together with the possible future it has to evaluate which of those alternatives would be preferable or desirable.

From a methodological point of view, it is an applied science: to solve specific problems it is necessary firstly to go in depth in the *prediction* — the “descriptive” level oriented to know the future —, to go subsequently to deal with the realm of *prescription* that is the one that gives guidelines to act.³⁷ So within the sciences of design related to web building the design or systems modelling oriented to problem solving has to start describing future events — prediction — before giving the step towards prescription.³⁸

But when there are social factors or variables involved, scientific prediction is much more difficult. This can lead to not very reliable predictions, and then they are not regarded for decision making in certain contexts. Despite or this, information science — as applied science — requires that any model developed for a practical application has to consider future factors. In this field as in other social and artificial human activities both action and no action could have important consequences.³⁹

Firstly we have to consider possible future events, even the ones with no desirable consequences, to go then to set a series of guidelines to lead our actions towards aims considered more laudable. In the methodological sequence that Simon suggests, the first step would be predict; then, from the conclusions of those predictive analysis we have to establish the behavioural guidelines to follow — the task of prescription — to get the wanted results. So, for this author, prediction and prescription are two methodological instruments used to “design our future.”⁴⁰

However, although both aspects take part in a future task they are clearly different: prediction is basically cognitive, while prescription moves into a volitive aspect, because it is linked to

³⁶ Cf. NINILUOTO, I., “Future Studies: Science or Art?,” *Futures*, v. 33, (2001), p. 373.

³⁷ About prediction and prescription in science see GONZALEZ, W. J., “Prediction as Scientific Test of Economics,” in GONZALEZ, W. J. and ALCOLEA, J. (eds.), *Contemporary Perspectives in Philosophy and Methodology of Science*, Netbiblo, A Coruña, 2006, pp. 83-112; and GONZALEZ, W. J., “Prediction and Prescription in Economics: A Philosophical and Methodological Approach,” *Theoria*, v. 13, n. 2, (1998), pp. 321-345.

³⁸ This topic is developed in SIMON, H. A., “Prediction and Prescription in Systems Modeling,” *Operations Research*, v. 38, (1990), pp. 7-14. Reprinted in SIMON, H. A., *Models of Bounded Rationality*. Vol. 3: *Empirically Grounded Economic Reason*, The MIT Press, Cambridge, MA, 1997, pp. 115-128.

³⁹ Cf. SIMON, H. A., “Why Economists Disagree?,” *Journal of Business Administration*, v. 18, n. 1-2, (1988/89), pp. 1-19.

⁴⁰ With respect to this, he pointed: “In an important sense, predicting the future is not really the task that faces us. After all, we, or at least the younger ones among us, are going to be a part of that future. Our task is not to predict the future; our task is to design a future for a sustainable and acceptable world, and then to devote our efforts to bringing that future about,” SIMON, H. A., “Forecasting the Future or Shaping it?,” *Industrial and Corporate Change*, v. 11, n. 3, (2002), p. 601.

guidelines for action. This second aspect has a direct relation to values — in a broad sense — because of the link between prescriptions and guidelines for action.

With relation to values, there are different taxonomies that try to classify them and that reflect a hierarchy so as they give information about the importance and influence of each in the different systems. But every value do not influence independently, they interact each other making combinations that are usually difficult to predict. However, it could be done a distinction in three levels: i) the way values influence in science in general; ii) the values typical of each scientific discipline (in this case, the ones related to web design); iii) the values people have independently, that in this context would be the users that interact in the internet.⁴¹

These values are of several kinds: ethical, social, cultural, economic, political, etc. They could influence the process of design in the three levels pointed: the aims, the processes, and the results.⁴² Related to aims, values intervene in the election of goals to solve specific problems; with relation to processes, values influence in the election of those means that are more appropriate to carry out the process of design; and related to results, values are employed to evaluate the final products.

From the beginning, the two scientific aspects that have an influence in the progress of web have followed a dynamic evolution: computational and informational. Also the technological aspect has a dynamic evolution. Again, there are two aspects at stake: the inner and the outer: a) the new designs contribute with new possibilities in every step of its advance; and b) the practical applications have a social reception — the individual and institutional users — and this has a positive effect in its development. With web a “revolution” has occurred that not only is social, economic or cultural, but also is a conceptual one: it has opened a diversification of the realm of informative contents, and this has strengthened what is called the “cognitive turn.”⁴³

In my opinion, we assist to a singular phenomenon from the perspective in the world context: every scientific advance related to web enable to make new practical applications. Once they have been incorporated by the communication and information technologies, almost immediately and in scattered places of the planet these advances turn into essentials for users. Then agents push again the process of research and creation of new products that open new horizons. This is possible because web is a vehicle that enables to share knowledge and transport it in real time.

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⁴¹ Cf. GONZALEZ, W. J., “De la Ciencia de la Economía a la Economía de la Ciencia: Marco conceptual de la reflexión metodológica y axiológica,” in AVILA, A., GONZALEZ, W. J. and MARQUÉS, G. (eds.), *Ciencia Económica y Economía de la Ciencia: Reflexiones filosófico-metodológicas*, FCE, Madrid, 2001, pp. 11-37.

⁴² Cf. GONZALEZ, W. J., “Economic Values in the Configuration of Science,” pp. 93-96.

⁴³ About the features of the “cognitive turn,” cf. GONZALEZ, W. J., “Novelty and Continuity in Philosophy and Methodology of Science,” in GONZALEZ, W. J. and ALCOLEA, J. (eds.), *Contemporary Perspectives in Philosophy and Methodology of Science*, pp. 1-28; especially, pp. 6-7.

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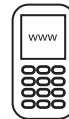


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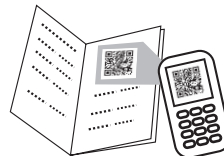
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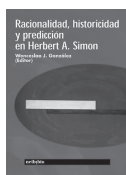
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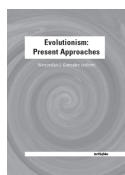
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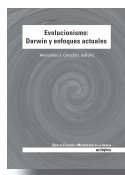
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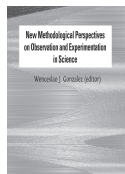
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