A Silent Revolution in Reflexivity[1]

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ABSTRACT

Currently, a transition from Science I, the traditional science regime from the 16th century onward to the turn of the 20th century, to Science II, the emerging new epistemic regime since 1900/1950, is on its way. This transition has been described, so far, as a complexity revolution. However, this transition can also be classified as a reflexivity revolution in multiple dimensions and practically across all scientific disciplines. Reflexivity is characterized by a circular configuration between two components x, y like in x causes y and y causes x or between a single building block like in $x \leftrightarrow x$. The current reflexivity revolution manifests itself, above all, in a new form of science, called second-order science, which fulfils vital functions for the overall science system in terms of quality control, of creating robust forms of knowledge and of providing challenging new research problems and large opportunities for innovations.

Keywords: Science I, Science II, reflexivity revolution, second-order science, zero-order science, new cybernetics

1 INTRODUCTION

This article focuses on deep contemporary reconfigurations of the global science system which have been classified as a transition from Science I to Science II (Hollingsworth/Müller, 2008). This transformation is largely based on a spectacular increase in complexity (Rescher, 1998) and, thus, as a complexity revolution. However, one can also detect a hidden dimension within Science II which was not discussed so far and which is concentrated on reflexivity and on circular reflexive relations.

This article advances the argument that Science II should be viewed as a recombination of a complexity and a reflexivity revolution. Moreover, due to the fundamental re-organization of the science system in general and an exchange in center-periphery relations across many dimensions of the science system, the present revolution can be qualified as an instance of a very rare Copernican revolution which reshapes the science system in most profound ways.

2 REFLEXIVITY AND CYBERNETICS

Due to its circular structure reflexivity was especially strongly promoted in the field of cybernetics where circular processes and feedback mechanisms played a decisive role in the formation and expansion of this field during the 1940s and 1950s. From the 1970s onwards second-order cyberneticians like Heinz von Foerster (1974, 2003, 2014), Ranulph Glanville (2009, 2011, 2014), Louis H. Kauffman (1987, 2005, 2009, 2009a) Bernard Scott (2011) or Stuart A. Umpleby (1990, 2007) were advocating reflexivity primarily in order to account for the roles and the impact of observers. For example, Heinz von Foerster described first-order cybernetics as the cybernetics of systems observed and second-order cybernetics as the cybernetics of observing systems. Likewise, Humberto R. Maturana and Francisco J. Varela (1987) stressed the principle that everything said is said by an observer. Stuart A. Umpleby advocated a new type of science which is based on the integration of observers (Umpleby, 2014). So it seems that reflexivity is mainly focused on observers and the need to include observers into the methodology of normal science where observers and observer-effects are mostly excluded.

But reflexive designs and analyses go well beyond the inclusion of observers, although observers constitute a significant element in reflexivity research (Widmer/ Schippers/West, 2009 or Müller, 2015). These reflexive configurations are not only related to observers, scientific or otherwise, to socio-economic systems or to the social sciences, including economics or science studies, but manifest themselves in very different contexts and across practically all scientific disciplines and sub-disciplines. A majority of reflexive designs and reflexive research is embedded in a new environment and in a new science level which provides the backbone of the ongoing reflexivity revolution.

Since the assertion above looks implausible, even at second sight, it will be advisable to start with the scientific revolution in complexity which is widely acknowledged also in terms of institutionalization and teaching programs.

3 THE CURRENT REVOLUTION IN SCIENCE AS A COMPLEXITY REVOLUTION

Science II refers to a new stage in the evolution of the science system as a whole which gradually replaces the science architecture of the last centuries which was based on theoretical physics as the leading scientific field, on the search for universal laws, on a reductionist methodology and on trivial machines and mechanisms as explanatory devices. Science I corresponds to the organization of science from its initial modern phase in the second half of the 15th century or 16th century up to the period from 1900 to 1950 approximately. Science I is the long-term period of majestic clockworks, culminating at an early stage with the "Principia Mathematica" of Sir Isaac Newton in 1687.

This old hegemonic science paradigm is more and more substituted by the architecture of Science II which is focused on pattern formation and pattern recognition, on the life sciences as emerging leading domain, on non-trivial machines and mechanisms and, finally, on more and more self-referential elements which were not admissible during the heydays of Science I. Table 1 summarizes some of the significant differences between Science I which lasted from the second half of the 15th century up to 1900/1950 and Science II as the new science architecture since the 1950s (See also Hollingsworth/Müller, 2008).[2]

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[1] Thanks go to Stuart A. Umpleby who provided very useful comments for an earlier version of this article.

[2] It should be added that Friedrich von Hayek presented a highly interesting specification of the nature of complex phenomena where he arrived at many of the differentiations which were used for Table 1 (Hayek, 1967, 1972).

Table 1 Main Differences between Science I and Science II along the Principal Component of Complexity

	Science I (1600 – 1900/ 1950)	Science II (from 1900/1950 onwards)
Leading Field	Classical physics	Evolutionary biology, the sciences of complexity
Theoretical Goal	General and universal laws	Pattern formation, Pattern recognition
Generative Mechanisms	Trivial	Non-trivial
Theoretical Perspectives	Axiomatic reductionist	Phenomena nested in multiple levels
Forecasting Capacities	High	Low
Complexity Levels	Low	High
Ontology	Dualism	Monism, with highly complex architectures
Perspective on Change	Static, linear, equilibrium states	Dynamism, systems operating far from equilibrium
Distribution of Events	"Mild" distributions and processes	"Wild" distributions, importance of rare and extreme events
Leading Metaphors	Clocks	Clouds

In contrast, Science II operates with blind watchmakers (Richard Dawkins) or, to use another metaphor from Karl R. Popper, works in a configuration of clouds. The leading discipline for Science I was theoretical physics whereas the core area of Science II are the life sciences, broadly conceived. Science II addresses a large number of common problems, common metaphors, common methods as well as common models and mechanisms. George Cowan identified a large set of issues that, contrary to the age of Science I, require the co-operative efforts of scientists across the Great Divides of natural, technical, medical and social sciences as well as the humanities:

> Theoretical neurophysics; the modeling of evolution, including the evolution of behavior; strategies to troublesome states of minds and associated higher brain functions; nonlinear systems dynamics, pattern recognition and human thought; fundamental physics, astronomy, and mathematics; archaeology, archaeometry, and forces leading to extinction of flourishing cultures; an integrated approach to information science; (or) the heterogeneity of genetic inventories of individuals. (Cowan, 1988:236)

Thus, the current revolution in science can be classified clearly as a revolution, with complexity as its principal component.

But one can find a second principal component within Science II which, so far, remained silent or hidden. To uncover this hidden component it will become necessary to highlight major changes in the overall science system from the 1950s to the year 2000.

4 MAJOR CHANGES IN THE SCIENCE SYSTEM, 1950 - 2000

Between the 1950s and today the science system changed in significant ways. From the infant days of second-order cybernetics between 1968 and 1974 and the 2010s several very large-scale transformations and shifts occurred within the overall science system which had a profound impact for different forms and levels of scientific practices.

Aside from the long-term growth of the global science system in terms of institutes, personnel or publications as an ongoing secular trend, the information infrastructures for science changed in a fundamental way, too. In the 1950s or 1960s the access to relevant scientific outputs, journals, research-projects and similar domains was very much restricted, being high in a few places with an advanced environment of universities, research institutes and libraries and being notoriously low or non-existent in most parts of the world. Today these restrictions are almost completely abolished and the access to recent scientific outputs, new journal articles, books, research reports and the like is very high even in remote areas of the world, due to the worldwide web and its enormous and still expanding contents. The technological support system for science has led to a considerable information overflow and even to an information anxiety (Wurman, 1989, Wurman *et al*., 2000) and can be expressed by a phrase of Jürgen Habermas as "neue Unübersichtlichkeit" ("new incomprehensibility" or, alternatively, "new intransparency").

Aside from the growth of the science system and its vastly expanded information infrastructures, the third very large-scale change came as a self-organizing attempt by scientists themselves to cope with the growing number of studies, tests, results and the like which used similar or identical designs, approaches or explanatory schemes and which differed only in time, space and in research groups from one another. This self-organized reaction can be summarized under a single heading, namely as meta-analysis[3] which was first proposed by Gene V. Glass, an

[3] On the group of early meta-analyses, see, for example, Glass/McGaw/Smith, 1981 Hedges/Olkin, 1985, Hunt, 1999 or Hunter/ Schmidt, 1990.

educational scientist, in the year 1976. Glass distinguished between primary and secondary data analysis on the one hand and meta-analysis on the other hand where he described a meta-analysis as a collection of all relevant studies on a highly comparable or identical topic and as a systematic analysis of the data pool of these studies. Glass introduced meta-analysis as "the analysis of analysis and as a statistical analysis of a large collection of analysis results from individual studies for the purpose of integrating the findings. It connotes a rigorous alternative to the casual, narrative discussions of research studies which typify our attempts to make sense of the rapidly expanding research literature." (Glass, 1976:3)

The table below shows that meta-analyses in psychology, for example, were practically absent during the 1960s and emerged one year after the publication of Gene V. Glass' article, albeit in a minimal version. By the mid-1980s however, meta-analyses turned out to be more frequent and from the 1990s onwards meta-analyses became an established research field within psychology, the social sciences (Wagner/Weiß, 2014), clinical research, economics, business administration, and many other areas. Meanwhile, meta-analyses cover all disciplines and fields across the entire scientific landscape. Meanwhile meta-analyses, due to their large and growing numbers in comparable fields, became objects for meta-meta-analyses and this process can continue, in principle, to even higher levels.

Table 2 'Meta-Analysis' as Keyword in Psychological Abstracts

Year	Number of Counts
1967 – 1976	0
1977	2
1978	4
1979	6
1980	9
1981	18
1982	32
1983	55
1984	63

Source: Hunter/Schmidt, 1990:40

From the 1980s onwards, more and more statistical methods and tools were developed which dealt with biases or spurious effects. The four important characteristics of meta-analyses lie in the following points.

- Meta-analyses are based on a large number of available, directly comparable and mostly quantitative studies.
- Additionally, meta-analyses are performed with partly new statistical methods and tools which were especially designed and developed for pooled data sets.[4]
- Moreover, meta-analyses moved out of their initial domains in psychology, medical research or education science and spread over practically all major science fields and disciplines, including the life sciences or theoretical physics.
- Finally, the prefix "meta" has acquired very different meanings when applied to first-order science domains. In areas like metalogic or metamathematics the prefix "meta" indicates foundational issues both for logic and for mathematics whereas metapsychology or metabiology[5] designate special fields within biology or psychology. It is partly for this reason that the new terms of second-order level and second-order science were chosen instead of the concepts of meta-level and combinations between "meta" and scientific disciplines or fields.

The fourth significant transformation in the overall science system occurred from the 1950s onward and this transformation was totally unrelated to the rise of meta-analyses. Research infrastructures experienced a significant take off in their institutionalization through the establishment of large-scale operations and organizations. CERN, for example, started its operations with a synchrocyclotron and a proton synchrotron during the 1950s, the nuclear research centre in Jülich in Germany was founded in 1956, etc. But these large-scale facilities were not restricted to disciplines like astronomy or high energy physics. In the 1960s social science data archives appeared on the European science map and observatories moved outside the field of astronomy to the oceans or to the arctic. In 2006, the European Strategy Forum on Research Infrastructures (ESFRI) produced its first map of future European research infrastructure facilities (ESFRI, 2006, 2008, 2010) which comprised an

4 On the current scope of meta-analysis, see Borenstein/Hedges/Higgins/Rothstein, 2009, Card, 2012, Cooper, H.M., 2009, Cooper/Hedges/Valentine, 2009, Egger/Davey-Smith/Altman, 2001, Higgins/Green, 2008, Hunter/Schmidt, 2014, Kulinskaya/Morgenthaler/ Staudte, 2009, Lipsey/Wilson, 2000, Petticrew/Roberts, 2006, Pigott, 2012, Rothstein/Sutton/Borenstein, 2005, Welton/Sutton/ Cooper/Abrams/Ades, 2012 or Whitehead, 2002.

5 Both metabiology and metapsychology remain first-order fields with special exploratory tasks. Metabiology can be considered as a recombination between genetics and algorithmic information theory and metapsychology has a clear focus on a client-centered settings with a strong emphasis on traumatic stress syndroms. On metabiology see, for example, Chaitin, 2009 and on metapsychology, see Gerbode, 2013.

ambitious program for new European research infrastructures across all relevant science fields.

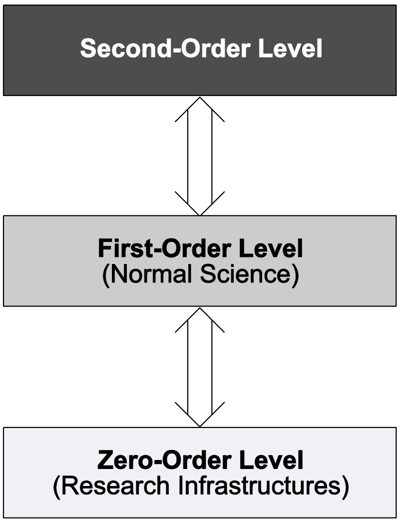
5 THE CURRENT REVOLUTION IN SCIENCE AS A SILENT REFLEXIVITY REVOLUTION

The combination of overall scientific growth in outputs, personnel and publications, an enormous expansion of access to scientific research in its inputs and outputs, the rise of meta-analyses and the institutionalized take-off of research infrastructures had significant effects on the basic architecture of science.

5.1 A Differentiation into Three Levels

In terms of levels, the science system underwent a differentiation from a single level into a three level configuration. According to this new scheme, modern science, after centuries of a single level organization, evolved from the mid-1950s up to the turn of the millennium to a three-level configuration, with a first-order level of conventional science research, supporting research infrastructures at a zero-order level and an area of reflexive analyses on first-order inputs or outputs at the second-order level. Figure 1 summarizes the new three-level configuration for contemporary science landscapes.

Figure 1 A New Architecture of Contemporary Science Landscapes: Three Principal Levels of Scientific Operations



The first-order level of research can be characterized in the tradition of Thomas S. Kuhn as a problem-solving operation and is designed for the exploration of the natural and social worlds as well as for the construction of a technological sphere and for the organization of the possible worlds of logic, mathematics and related normative fields. Scientific research at the first-order level or domain can be defined as first-order science and it constitutes the reference area for scientific activities. Investigations on empirical themes across nature and society, on technical or technological systems or on normative issues in logic, mathematics, statistics, ethics or aesthetics fall all under the category of first-order science. Approximately 90% of scientific activities are still undertaken at the first-order level or domain.

Research infrastructures became a special support-level for science over the last decades only. This zero-order level constitutes the expanding kingdom of research infrastructures which perform vital catalytic functions of enabling or of accelerating first-order research. The different catalytic functions of research infrastructures are accomplished in three different forms.

- The first type is based on large-scale observation, measurement and experimental facilities and their production of a rich data variety which contains relevant observations, measurements and experimental data for first-order research.
- The second form builds and utilizes a rich coded information base which is composed of bibliometric and scientometric documentations.
- Finally, the third type operates with the documentation and the archiving of relevant research data or documents and through the institutionalization of permanent data or document archives.

All three forms combined constitute the zero-order level of science landscapes and constitute the area of zero-order science which, moreover, should increase in relevance during the next decades. In terms of disciplines research infrastructures are operative for clusters of scientific disciplines, not for a single discipline or field. For example, the ESFRI-roadmap 2010 distinguished between research infrastructures for six broad disciplinary clusters, namely for the social sciences and humanities, biological and medical sciences, the environmental sciences, materials and analytical facilities, energy sciences, and physical sciences and engineering.

Research at the second-order level goes far beyond meta-analyses and operates generally on various building blocks from first order science like experimental results, tests, studies, evaluations, models, methods, theories and the like with scientific means. These building blocks can be on the input side of first order research like theories, models, methods, designs or methodologies or on the output side like tests, patterns, causal relations, hypotheses and hypotheses-groups, functions, correlations, model results, scenarios, and the like. Research at the second-order level can be organized in a multiplicity of contexts and offers important functions for the overall science system in its current stage (see also Müller/Riegler, 2014, 2014a). In the next section second-order science will be presented in its major characteristics and functions.

5.2 Four Examples of Second-order Science

The overview of second-order science starts with four examples from very different scientific disciplines, namely from sociology, from theoretical physics, from a cluster of disciplines like economics, earth sciences or linguistics, and, finally, from innovation studies. Moreover, the four examples of second-order science are focused on different building blocks, namely on theoretical concepts, on models, on generative mechanisms, and, finally, on explanation sketches. Additionally, these four examples require different tools and methods of analysis in order to accomplish a conceptual second-order study, a second-order model-investigation, an analysis of second-order generative mechanisms and, finally, a second-order explanation sketch. These four examples should make it clear that second-order science transcends the boundaries of meta-analyses and is capable of moving into many *terrae incognitae*.

Second-order conceptual analysis: a quality of life analysis of quality of life-analyses

For the first instance one has to select a theoretical concept from first-order science and collect a number of first-order studies for this theoretic concept. Taking quality of life as concrete example from the social sciences, questionnaires and operationalization for quality of life exceed the two digit domain and have become very numerous.[6] One of the possibilities for a second-order conceptual study lies in the specification of a general quality of life scheme which, due to its new categorizations, is capable of integrating the numerous versions of quality of life into a consistent format. Such a general second-order frame will most probably find robust and evolutionary stable classifications (Müller, 2013) which are capable of accounting for the large diversity of available variables and dimensions at the first-order level.

Second-order modeling: a model of models

From the 1970s onwards theoretical physicists at the University of Stuttgart developed highly general non-linear and complex models which were based on meanfield-theories or master-equations which could be applied to a large number of very different domains like laser research, migration processes or long-term economic cycles (Haag, 1989, Haken 1977, 1983 or Weidlich, 2000). Moreover, the master equation approach was found to be able to serve as the foundation of other types of models (Helbing, 1993) and as a basic model for other model groups. Research tasks in the area of models of models are numerous and divers. Recently, Michael Lissack proposed variations with *ceteris paribus* assumptions in models as fruitful second-order modeling designs (Lissack, 2015).

Second-order generative mechanisms: a generative mechanism of generative mechanisms

One of the fascinating aspects of studies in self-organization lies in the wide diffusion of power-law distributions across many different domains like ecological systems, earthquakes, migration processes, scientific citations, etc. Complex networks[7] were recognized as one of the important mechanisms for this type of distribution. But other forms of generative mechanisms like self-organized criticality (Bak, 1996, Jensen, 1998) were identified as well. A second-order investigation (Kajfež-Bogataj/Müller/Svetlik/Toš, 2010) searches for a more general format of a generative mechanism which is capable of generating these different generative mechanisms.

Second-order studies with a common topic: An innovation sketch of innovation sketches

The fourth example uses studies on success factors of innovations as its reference point. After the compilation of a large number of innovation studies the next analytical step consists of an ordering of these studies in a comprehensive explanation sketch. The final step of this type of second-order analysis lies in a presentation of a highly general explanation sketch which can be tested and analyzed by first-order innovation research with respect to its robustness and to its further empirical implications. (See, for example, Damanpour, 1991, Rosenbusch/Brinckmann/Bausch, 2011 or Evanschitzky/Eisend/ Calantone/Yuanyuan, 2012)

5.3 Scope of Second-order Science

Like zero- or first-order science, second-order science is bound to a specific level within the stratified science landscapes Second-order science as the sum total of research activities that are carried out at the second-order level can be described, on the one hand, with respect to its topics and issues and, on the other hand, in an institutional way with respect to its potential disciplines.

[6] On the variety of approaches to quality of life, see Amann, 2010, Bowling, 2005, Knecht, 2010, Morris, 2013, Nussbaum, 2011, Nussbaum/ Sen, 1993, Phillips, 2006, Rapley, 2008, Sandel, 2009, 2012, Sen, 2012, Skidelsky/Skidelsky, 2012, Stiglitz/Sen/Fitoussi, 2010 or Stiglitz, 2012.

[7] See Barabasi, 2002, 2010, Newman/Barabasi/Watts, 2006, Sornette, 2003, 2006 or Watts, 1999, 2003.

The choice of research topics in the second-order domain is based on a single operation, *i.e*., the operation of re-entries, which was originally suggested by George Spencer Brown (1969). The operation of re-entry occurs whenever elements or building blocks from the first-order level are applied to themselves in the form of

> computation of computation, cybernetics of cybernetics, geometry of geometry, linguistics of linguistics, logic of logic, magic of magic, mathematics of mathematics, pattern of pattern, teaching of teaching, will of will. (Kauffman, 2005:129)

Similarly, Heinz von Foerster (2003) referred to processes like "understanding understanding," or "learning learning" and to topics like "communication of communication," "goals of goals," "control of control," etc. These self-applications of first-order science building blocks accomplish a dual reference because these elements are not only applied in various space-time settings, but also to themselves. In a more formal way a first-order science building block X with a re-entry operation RE produces X[X]:

$$X \rightarrow RE \rightarrow X[X]$$

Potential topics for second-order science can be generated in practically infinite numbers. Moreover, each second-order topic can be analysed with different research designs and methods and is not restricted to a single path of analysis. Finally, second-order analyses should be particularly useful for complex societal topics and problems which can be characterized as so-called wicked problems. (Alrøe/Noe, 2014)

With respect to second-order disciplines and fields one can construct a very large number of new fields or disciplines for the second-order level because these re-entries can be undertaken within all scientific disciplines, sub-disciplines, discipline groups or hybrid fields of the first-order level. A first-order field X can be transformed, *via* re-entry RE, to a second-order field X [X]

$$X \rightarrow RE \rightarrow X[X]$$

In general, second-order domains or fields are distributed across the same range of scientific disciplines and sub-disciplines which are used for the first-order level. One can put forward a *correspondence principle* stating that each institutionalized field at the first-order level has, in principle, a corresponding counterpart at the second-order level that could be organized as a new research and teaching program in the future. The correspondence principle can be extended from scientific disciplines hybrid fields and to discipline clusters and groups as well which are used in the classification of first order science. The following five examples are based on this correspondence principle between first- and second-order disciplines.

The first type produces re-entries in well-established scientific disciplines like political science, chemistry, sociology, historiography, management science or engineering and leads to new disciplines like second-order political science, second-order chemistry, second-order sociology, etc. Second-order sociology, for example, is based on the work of first-order sociology and strives for higher levels of robustness in sociological knowledge, deeper foundations for sociological models and mechanisms or more general theories. Second-order management science produces second-order schemes for theoretical concepts in management science and focuses on robust relations and functions on various management issues or problems. Usually, these re-entries into first-order disciplinary domains lead to new second-order disciplines which at the present time are only marginally explored.

The second type focuses on hybrid first-order fields like socio-economics, situated cognition or health care and industrial engineering and creates the corresponding hybrid disciplines of second-order socio-economics or second-order situated cognition. Evidently, hybrid fields must be well-established over several decades. Socio-economics, for example, is organized in the "Association for Socio-Economics" which dates back to the year 1941 or the „Society for the Advancement of Socio-Economics“ (SASE) which was founded by Amitai Etzioni in the year 1989. Both societies have developed a dense network of socio-economic topics, operate on a global scale, use a large amount of theoretical and modeling approaches and support several journals like the "Review of Social Economy", "The Forum for Social Economics" or the "Socio-Economic Review"and qualify, thus, as a potential second-order field.

The third type starts with large clusters of disciplines like the social sciences, the natural sciences or the humanities and uses re-entries to construct the new disciplinary clusters of second-order social sciences, second-order humanities or second-order natural sciences. Second-order social sciences can be focused, for example, on the inputs of different social science disciplines and on potential deep conceptual or model structures.

The fourth type focuses either on a first-order normative discipline like mathematics, logic, law or philosophy of science or on the normative sciences altogether. Second-order mathematics could have its focus on foundational issues like algebras of algebras, geometry of geometries or arithmetic of arithmetics. Second-order normative sciences could be concentrated on a methodology of methodologies, research designs of research designs, rule-systems of rule systems, laws of laws, etc. Usually, these second-order normative studies should lead to normative approaches with higher generality, directed towards new foundations of normative sciences.

Finally, the fifth type of re-entries falls outside the four previous examples which are based on well-established first-order disciplines or discipline groups. The fifth type can be focused on a special theme which can be found across many first-order disciplines. For example, a focus on the routines or practices of observers can generate a new second-order discipline on scientific observers. Such a focus brings a reflexive shift towards a more general understanding of researchers, their recurrent research operations and their changing work environments which are based on first-order studies of observers across various disciplines. Obviously, researchers of radical constructivism or second-order cybernetics and their operations would be a part of such a second-order discipline, too.

These five types of re-entries for different disciplinary fields of first-order science are just a small and tiny fraction of possible re-entries. In general, re-entries can be used to establish new academic fields with a second-order research program and curriculum. These research and teaching programs can be built, due to the correspondence principle, in practically all institutionalized fields and disciplines of first-order science. Research and teaching programs in second-order sociology, in second-order formal sciences, in second-order clinical and health research, in second-order anthropology and in many more fields and disciplines can and should be established in the years and decades ahead as the institutional basis of second-order science.

5.4 A General Methodology of Second-Order Science

The general methodology of second-order science can be presented with the help of a typical second-order analysis within the social sciences. In recent years big comparative data sets on attitudes and living conditions across Europe were produced as a central activity of zero-order science and were included in the ESFRI-roadmap of 2006 and have become a European Research Infrastructure Consortium (ERIC). The availability of these data sets like the European Social Survey (ESS) led to a large number of more than 3000 articles which demonstrates the high utility of this form of dada production for comparative research.

In a recent publication, Brina Malnar and Karl H. Müller (2015) selected these approximately 3000 ESS-articles as first-order building block X and produced an ESS-analysis of these first-order ESS-analyses X[X]. The goals for this analysis were specified as the construction of a profile of ESS-users on the one hand and on ESS-utilizations on the other hand. A data-base for these ESS-articles was built which used variables like the nationality of the authors of ESS-articles, the academic disciplines of the authors, the topics of the study, the ESS-variable groups used for the study or the number of ESS-rounds that were studied. In a final step these variables were analyzed mainly with the methods from descriptive statistics which yielded the user-profiles of ESS-researchers and the utilization profiles for ESS-data.

One can generalize this example to a general methodology for second-order science investigations which should include the subsequent steps for any particular building block X from first-order science like a concept, relation, theory, model, test, generative mechanism, scientific field, etc. Table 3 demonstrates the necessary methodological steps for an analysis of X[X]. On the left side of Table 3 one finds the necessary or optional steps for a general methodology of second-order science in terms of basic recombination operators, the second column presents a short description of these specific operations.

Table 3 Core Steps for a General Methodology of Second-Order Science

Recombination Operations	Description of the Operations
Selecting X	Consensus on a common first-order theme X
Re-entry X	A re-entry operation in the first-order theme and the creation of a corresponding second-order topic
Adding Goals[X]	Consensus on the goals of the observer(s)
Widening X[First Order Building] Blocks]	The compilation of a large number of first-order building blocks on the common theme
Ordering X[First-Order Building Blocks]	Applying various methods for a re-arrangement of first-order building blocks like data-bases, new conceptual schemes, etc.
X(X):{Integrating, Deepening, etc. First Order Building Blocks}	The core part of second-order analysis which, in dependence from the goal set, integrates, heightens, deepens first-order building blocks and which produces a final output.
Adding [Impact X(X) $\rightarrow$ X[First-Order Science]	Generating building blocks for first-order science and assessing the effects of the final second-order outcomes for first-order research on the common theme X.
Adding [X(X) $\leftrightarrow$ Society/Environment-Relations & Dynamics (optional)]	An evaluation of the relations between the outputs of second-order research on X(X) or of X and the wider environment across science and society and their dynamic patterns

5.5 Functions and Goals for Second-Order Science

The rise of second-order science can be viewed as a reflexive turn and as a self-organized reaction within the science system itself to reduce the complexities and negative side-effects of the spectacular growth processes of first-order science.

Table 4 exhibits various dimensions of Science II which can be subsumed under the principal component of reflexivity.

Table 4 Main Differences between Science I and Science II along the Principal Component of Reflexivity

	Science I (1600 – 1900/) 1950	Science II (from 1900/1950 onwards)
Second-Order Science	Implicit	Highly Advanced
Zero-order Science	Implicit	Highly Advanced
Distances betw. Social Sciences Natural Sciences	High	Low - Medium
Potential for Interdisciplinary Co-operation	Low	High
Methodological Goals	Objectivity, Accessibility	Intersubjective Reproducibility
Observers	Excluded	Included
Main Episte-mology	Exo-Mode	Endo-Mode
Self-Reference	Excluded	Included
Reflexive Designs	Peripheral	Central
Sources of Novelty	Nature, Societies	Nature, Societies | First-Order Science
Core Philosophers	René Descartes	Ludwig Wittgenstein

Although only a single article can be found which combines the concepts of reflexivity and revolution in its title (West, 2000), the rise of second-order science can be seen as the core element in an ongoing reflexivity revolution. Moreover, second-order science fulfils vital functions and goals for the sustainabilitly of the overall science system.

Second-order science becomes necessary for the quality control of the overall science system and for the production of robust knowledge which is based on a rigorous analytical, statistical or model analysis of the inputs and outputs of first-order science.

Second-order science fulfils an important role for the innovation capacity of the overall science system through the heuristic strategies of second-order science like integration, deepening, widening, re-ordering, etc. which provide more general frameworks or a generative deep-structure to first-order theories, models or mechanisms.

Additionally, second-order science advances the robustness of the results of first-order science through the integration of building blocks from first-order science.

Thus, first-order and second-order science will organize themselves in a recursively closed manner where the outputs or inputs of first-order science are transformed into new second-order inputs and the outputs of second-order science become new inputs for first-order science which can lead to new outputs for second-order science, *round and round* …., until eigenforms across first- and second-order science emerge.

The leading aphorisms for this reflexivity revolution which combine traditional or first-order science and second-order science can be constructed in the following way:

- First-order science: the science of exploring the world
- Second-order science: the science of reflecting on these explorations

6 THE CURRENT COMPLEXITY AND REFLEXIVITY REVOLUTION AS A COPERNICAN REVOLUTION

It has been argued that the current shift to Science II is dependent on two principal components, namely on complexity and reflexivity where each of these principal components can be described with a large number of dimensions, as shown in Table 1 and in Table 4. As an additional classification, the current transition in science qualifies also as a Copernican revolution.

The phenomenon of a Copernican revolution constitutes a very rare event in the long-term history of science and can be characterized by a significant number of exchanges in center-periphery relations. Elements in the center of an old epistemic regime move to the periphery and peripheral components shift to a center position within the new regime. In terms of Copernican inversions along the complexity dimensions, these shifts manifest themselves in the transitions from linear to non-linear models, from universal laws to patterns or from trivial to non-trivial machines. With respect to reflexivity dimensions, these shifts can be seen in the exchange from objective to observer-dependent research, from the exclusion of self-reference to its inclusion or from the implicit status of second-order science to its central and highly advanced form.

This contemporary shift from Science I to Science II can and should be classified, due to its profoundness, its multi-dimensionality and its exchange in center-periphery relations as one of the very rare instances of a Copernican revolution.

Table 5 summarizes the three big Copernican revolutions in the evolution of the global science system. As can be seen from Table 5, these three Copernican revolutions are classified chronologically as a rationality revolution in ancient Greece from the Pre-Socratics to Aristotle, as a revolution in methodology, designs and tools or instruments during the Renaissance period, and, finally, as a revolution in complexity and reflexivity where the part of the reflexivity revolution remains, at least until now, implicit and hidden only.

Table 5 Three Copernican Revolutions in the Evolution of Science

Time-Scale	Copernican Revolutions
800 - 400 B.C.	Copernican Revolution I: A Revolution in Rationality and Logical Reasoning about the World by Its Observers
1450/1600	Copernican Revolution II: A Revolution in Methodology, Designs and Tools Exploring the World (from Without) with Observations, Instruments, Experiments and Support from Previous Results Inverting a Geocentric System with a Heliocentric System
1950 2050	Copernican Revolution III: A Revolution in Complexity and Reflexivity Reflecting on the Explora-tions from First-Order Science (from Within) at the Second-Order Level

The first Copernican revolution was a revolution in thinking and styles of thought, the second one a revolution in exploring the world and the third one a revolution in complex explorations and in reflecting on these complex explorations.

7 SECOND-ORDER SCIENCE AND NEW CYBERNETICS

New cybernetics can be introduced as a novel approach, apart from second-order cybernetics, but within the research tradition of radical constructivism (On varieties of radical constructivism, see Riegler, 2015). New cybernetics pursues as its primary goals the support of second-order science with new tools and instruments, the proliferation of highly innovative topics, of grand challenges and of innovation outlets for the expansion of second-order science, and, finally, the assistance in the institutionalization of second-order science both in the domain of institutes, departments or centers and in the field of teaching programs and curricula development.

Thus, the two aphorisms above can be completed with a third one on new cybernetics.

- First-order science: the science of exploring the world
- Second-order science: the science of reflecting on these explorations
- New cybernetics: the science of reflecting on these reflections

The new frontiers of second-order science and of new cybernetics will lead to a new and rich configuration for scientific reflexivity which will become considerably advanced and diversified in the years and decades ahead.

8 OUTLOOKS

It remains, of course, for the reader to decide whether this article succeeded in promoting the perspective of a Copernican revolution in science and of the emergence of second-order science as the most significant element in reflexive research designs or whether this grand narrative of a revolution in reflexivity is still as obscure or unconvincing as before.

At least the overall argument on the rise of circular or reflexive formations can be presented in a reflexive formation as well. Old cybernetics started the wider scientific interest in circularity with the meetings of the Macy Foundation on “circular causal and feedback mechanisms” in the 1940s. But old cybernetics was marginalized in the course of the 1970s and 1980s and played only a peripheral role. However, the large-scale expansion of the global science system in the last decades led to a self-organized formation of second-order science. The emergence and expansion of second-order science constitutes the most important element in the contemporary reflexivity revolution which will become also more and more institutionalized in the decades ahead. Second-order science, in turn, should be accompanied with the rebirth or renaissance of cybernetics in the form of new cybernetics which could become the major pump for tool-development, methodologies and innovations for second-order science and which should provide the necessary support for its sustainable evolution and expansion.

After all, old cybernetics started this reflexivity revolution and new cybernetics, due to the downfall of traditional cybernetics, should become central for its expansion.

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