Second-order Science: A Vast and Largely Unexplored Science Frontier

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> Context • Many recent research areas such as human cognition and quantum physics call the observer-independence of traditional science into question. Also, there is a growing need for self-reflexivity in science, i.e., a science that reflects on its own outcomes and products. **> Problem** • We introduce the concept of second-order science that is based on the operation of re-entry. Our goal is to provide an overview of this largely unexplored science domain and of potential approaches in second-order fields. **> Method** • We provide the necessary conceptual groundwork for explorations in second-order science, in which we discuss the differences between first- and second-order science and where we present a roadmap for second-order science. The article operates mainly with conceptual differentiations such as the separation between three seemingly identical concepts such as Science II, Science 2.0 and second-order science. **> Results** • Compared with first-order science, the potential of second-order science lies in 1. higher levels of novelty and innovations, 2. higher levels of robustness and 3. wider integration as well as higher generality. As first-order science advances, second-order science, with re-entry as its basic operation, provides three vital functions for first-order science, namely a rich source of novelty and innovation, the necessary quality control and greater integration and generality. **> Implications** • Second-order science should be viewed as a major expansion of traditional scientific fields and as a scientific breakthrough towards a new wave of innovative research. **> Constructivist content** • Second-order science has strong ties with radical constructivism, which can be qualified as the most important root/origin of second-order science. Moreover, it will be argued that a new form of cybernetics is needed to cope with the new problems and challenges of second-order science. **> Key words** • **Philosophy of science, methodology of science, first-order science, second-order science, Science 2.0, Science II, new cybernetics, second-order cybernetics, scientific novelty, re-entry.**

Introduction

« 1 » In this article we introduce the concept of second-order science, its scope and its major functions for the science system in general. We start with the differentiation between three seemingly identical concepts, namely Science 2.0, Science II and second-order science. Next, we provide the necessary conceptual groundwork for the crucial differentiation between first- and second-order science. Further on, we present a research agenda for the vast and largely unexplored landscapes of second-order science. We argue that the area in which second-order science operates should be viewed as a major expansion of traditional scientific fields, as a scientific breakthrough towards a new wave of innovative research and as a new phase for trans-disciplinary research. We conclude with a brief discussion of the implications of second-order science for radical constructivism on the one hand and cybernetics on the other.

Science 2.0, Science II, and second-order science: Basic distinctions

« 2 » In the recent literature, two seemingly synonymous terms for second-order science can be found: "Science 2.0" (Nentwich & König 2012; Nielsen 2011; Waldorp 2008) and "Science II" (Hollingsworth & Müller 2008; Müller & Toš 2012: 21–61; Umpleby 2011). We argue that Science 2.0, Science II and second-order science are to be considered as separate domains within significantly different contexts.

« 3 » Science 2.0 addresses the growing potential for scientific co-operation with the tools and instruments of Web 2.0. Ben Shneiderman sees in Science 2.0 a new era of disciplinary, inter- and trans-disciplinary co-operations:

> "Successful scientific collaboratories among genomic researchers, engineering innovations through open-source software, and community-based participation in cultural heritage projects are all early indicators of the transformative nature of collaboration." (Shneiderman 2008: 1349)

« 4 » For Shneiderman, Science 1.0 refers to the traditional forms of network building, face to face interactions, co-operations and exchanges from the beginnings of modern science up to the end of the 20th century. Science 2.0 is now emerging, and is changing scientific production, interaction and co-operation processes from its traditional local and face to face formats to new, space-independent global forms. Additionally, Science 2.0 should also boost inter- and trans-disciplinary communication and co-operation, due to the open access to materials by other researchers, to an easy cross-border entrance without the usual disciplinary barriers and to user-friendly web-formats and web-based research infrastructures.

« 5 » An additional dimension of Science 2.0 refers to new methods and tools for the study of web-based socio-technical

	Science I	Science II
Leading science field	Classical physics	Evolutionary biology, the sciences of complexity
Theoretical goal	General, universal laws	Pattern formation and 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	Dynamism, openness of systems, equilibrium states operating far from equilibrium
Distribution of events and processes	"Mild" distributions	"Wild" distributions, importance of rare and extreme events
Potential for interdisciplinary co-operation	Low	High
Leading metaphors	Clocks	Clouds
Cognitive distance between social and natural sciences	High	Medium
Observers	Excluded	Included
Self-reference	Excluded	Included
Second-order science	Marginal	Highly Advanced
Paradigmatic philosopher	René Descartes	(Late) Ludwig Wittgenstein

Table 1 • Main differences between Science I and Science II.

systems and their dynamics. In situations such as natural disasters, communication and co-ordination processes become central for successful relief operations. Within this context, Science 2.0 can provide the necessary web support for organizing these communication and co-ordination processes. At the same time, researchers obtain, in the case of a natural disaster, the necessary data to study and analyze the dynamics of these processes.

« 6 » Science II refers to a new stage in the evolution of science as a whole, gradually replacing Science I, i.e, the science architecture from the 16th century up to 1900/1950, which

- was based on theoretical physics as the leading scientific field,
- searched for universal laws and
- for the most part, used a reductionist methodology and trivial machines and mechanisms as explanatory devices.

« 7 » By contrast, Science II, as the new science architecture since the 1950s (Hollingsworth & Müller 2008), focuses on pattern formation and pattern recognition, on the life sciences as the emerging leading domain, on non-trivial machines and mechanisms and, finally, on more and more self-referential elements that were not admissible during the heyday of Science I. Table 1 summarizes some of the significant differences between Science I and Science II.[1]

« 8 » As can be seen from Table 1, the status of second-order science is raised from its marginal importance in Science I to a position of central relevance in contemporary Science II. So what exactly do we mean by this concept, and what are its scope, its potential and its functions?

A new architecture of contemporary science levels or science domains

« 9 » This section introduces a general architecture for Science II based on different vertical levels or, equivalently, horizontal domains and on the evolution of a three-domain/level configuration for the contemporary science system in general (Figure 1).[2] According to this scheme, modern science evolved, for centuries implicitly and since the end of the 19th century explicitly, as a triple-domain/level complex between conventional science or research at a first-order domain/level, supporting research infrastructures at a zero-order domain/level and an area of reflexive analyses of first-order scientific research at a second-order domain/level.

1| Friedrich von Hayek (1967) presented a specification of the nature of complex phenomena, where he arrived at many of the differentiations that were used for Table 1.

2| Usually, the three areas in Figure 1 are conceptualized as different *vertical levels*, following the distinctions between levels and meta-levels, analyses and meta-analyses, research and research infrastructure, etc. Here, we want to emphasize that these vertical distinctions are not the only possible solution and an equivalent conceptualization as well as visualization can be provided in terms of three different *horizontal domains*. With this, we want to forestall hierarchical interpretations of higher levels as superior and more important than lower levels. Therefore we refer to the dual notion of "domains/levels" in the remainder of the paper.

Figure 1 • Three principal domains/levels of science landscapes.

Figure 2 • Three domains/levels of science landscapes around 1950/1960.

« 10 » The first-order domain/level of research can be characterized as an exploratory problem-solving operation. It is designed, on the one hand, for the exploration of the natural and social worlds as well as for the construction of a technological sphere and, on the other hand, for the axiomatization and orderings of the possible worlds of logic, mathematics and related normative fields. The first-order domain/level of research constitutes the usual 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 all fall under the category of first-order science. The large majority of scientific activities are still undertaken in the first-order domain.[3] Finally, scientific research in the first-order domain can be defined as first-order science.[4]

« 11 » The zero-order domain constitutes the realm of research infrastructures, which performs vital catalytic functions of enabling, accelerating or improving first-order research. These different catalytic functions are accomplished, mainly in three different forms. The first type is based on large-scale observation, measurement and experimental facilities and their production of a rich variety of data that contains relevant observations, measurements and experimental data for first-order research. The second form builds and utilizes rich coded[5] information bases that are composed of bibliometric, scientometric, genomic or other types of coded documentations. Finally, the third type becomes especially relevant for the social sciences and humanities and operates with the documentation and archiving of relevant research data or digitalized documents and through the institutionalization of permanent data or document archives. All three forms combined constitute the area of zero-order science, which, moreover, should increase in relevance in the age of Science II.[6]

« 12 » In contrast, the fields in the second-order domain operate on building blocks from the first-order level such as experimental results, tests, studies, evaluations, models, methods, theories and the like with scientific means. Research in the second-order domain can be organized in a multiplicity of contexts and corresponds in its diversity to the first-order domain/level. By generating new topics and fields in the second-order domain, second-order studies offer important functions for first-order research, as described later in this article.[7]

« 13 » Figure 2 exhibits a stylized horizontal image of these three domains around the decades between 1940 and 1960, when trans-disciplinary approaches such as systems science, cybernetics or artificial intelligence emerged. Following Figure 2, little science entered a period of big science (de Solla Price 1963), with high levels of production and publication levels.[8] The dominant field in the second-order domain was occupied by an expanding philosophy of science and the research infrastructures in the zero-order domain shifted from small-scale into large-scale configurations. For example, CERN started its operations with a synchro-cyclotron and a proton synchrotron during the 1950s, and the nuclear research center in Jülich was founded in 1956.

« 14 » At this point we can define second-order science as the pool of academic fields in the second-order domain/level or, operationally, as the sum total of research activities that are carried out in the second-order domain/level. Like zero- or first-order science, second-order science is, thus,

3| Taking the ratio between EU budgets for research and technology and for research infrastructures, one arrives at figures in the range of 10% for research infrastructures. Currently, only marginal funding is provided for second-order science studies.

4| Note that first-order science is not simply the same as Thomas Kuhn's "normal science." Kuhn distinguished between a phase of normal science (working within a paradigm) and a phase of crisis or revolutionary science (working on the selection of a new paradigm). In our sense, first-order science covers the period of normal science *and* revolutionary science.

5| Coded objects comprise publications, gray literature and citations in the science world, but can be extended to coded genetic information in bio-technology, etc.

6| Note that the zero-order domain/level is not simply concerned with data and metadata gathering in the sense of description and classification. Rather, it produces research services that go very far beyond data gathering, such as high-power computer services, infrastructures for nanotechnology, etc. Such research infrastructures have become a well-defined area with a high diversity in activities and outputs and should *not* be reduced to data gathering.

7| It must be added that a small area at the second-order level or domain is reserved for second-order data and information analyses from the zero-order level or domain, such as meta-data compilations or bibliographies of bibliographies, and increasingly also meta-data of meta-data of meta-data, etc.

8| "Little science" set out to explore the natural and social worlds with high returns of novelty. Within "big science" or "big e-science" the science system becomes more and more confronted with the effects of its own products, objects, technological designs, evaluations, etc.

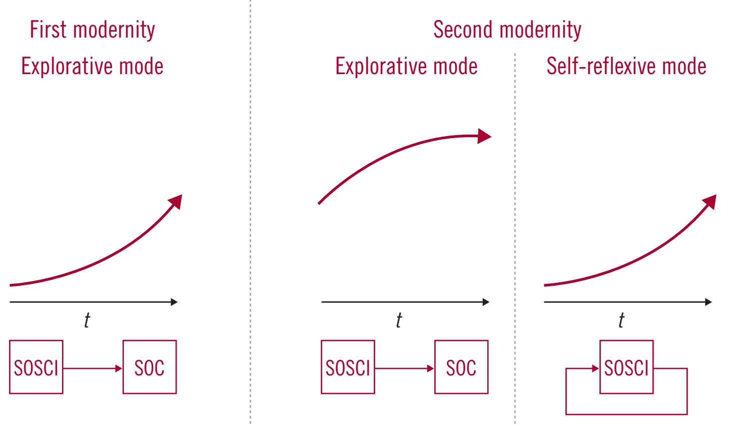


Figure 3 • An inversion of novelty in the social sciences within contemporary and future science landscapes. SOSCI: social sciences; SOC: society; vertical axis: increases in novelty/innovations. The arrow from SOSCI → SOC refers to the fact that social sciences deal exploratively with their societies. SOSCI → SOSCI, then, means that social sciences deal reflexively with their own results. Note that the shape of the curves assumes a logistic form that is typical for innovation and diffusion processes and is not based on actual data (Müller 2013a, 2013c).

bound to a specific domain/level of the overall science landscape.

« 15 » Due to its domain/level of investigation and its dependence on the building blocks of first-order science, second-order science is necessarily reflexive. Originally, reflexivity, along with concepts such as self-reference, was mostly excluded from research during the period of Science I, due to their inherent logical barriers and paradoxes. As can be seen in Table 1, reflexivity and self-reference change from their highly peripheral status in Science I into a core position in Science II. In this sense, Science II, second-order science and reflexivity, together with other self-related notions, become intertwined and connected in multiple and very dense ways.

Inversions of scientific novelty

« 16 » In the past, first-order science worked rather well, productively and innovatively. So what makes research in the second-order domain so important if not indispensible? In his books on "risk society," Ulrich Beck (1986, 2000) points to a phase transition of the science system in general to a new stage, which he qualifies as "reflexive." In the first period of modernity, Science I, organized as "little science," set out to explore the natural and social worlds with high returns of novelty. In "big science," and especially in big e-science of Science II, the science system becomes increasingly confronted with the effects of its own products, objects, technological designs, evaluations, interventions, etc. So science must be increasingly concerned about its own internal and external effects, and thereby become more aware of its own consequences and, at the same time, more self-reflexive in terms of its wider implications for societies and their environments.

« 17 » Beck assumes a phase transition in science towards a reflexive or self-reflexive state in terms of science studies on the effects and consequences of the objects and interventions of science. In addition, we propose an important inversion where, generally speaking, inversions can be characterized by an exchange of centre and periphery relations (as was the case in early astronomy, where the relation between Earth and the sun was inverted to the heliocentric system). This change can be described as an inversion of novelty and assumes a shift in the sources of scientific inventions, innovations and radical breakthroughs (Hollingsworth & Hollingsworth 2011) from the dominant mode of exploring the world to the reflexive mode of focusing on the already available scientific outputs, resources, publications and the like. Moreover, this inversion of novelty should also have significant implications for science policy and for teaching or curricula developments. Figure 3 captures several of the characteristic elements of this novelty inversion, with a focus on the social sciences.[9]

« 18 » On the left-hand side of Figure 3, one can see the expansion of first-order social sciences in their explorative mode on the social and societal worlds, which is represented by the lower half of an S-shaped curve, with high increases in novelty or social science innovations.

« 19 » The inversion of novelty comes about in the right-hand part of Figure 3, which shows that novelty in the social sciences is based to a diminishing extent on the advances of first-order social sciences, on the exploration of new topics and domains or on the construction of new models or theories. Rather, high levels of novelty and innovation in the social sciences occur in second-order analyses of already completed first-order social science elements.

« 20 » This inversion of novelty can be supported with the help of three examples from different first-order domains, again taken from the social sciences.

« 21 » *Example 1*: With respect to theoretical concepts in the social sciences such as standards of living and quality of life, it becomes increasingly difficult – due to a rich variety of current specifications[10] of and questionnaires on standards of living or quality of life – to produce significant new insights through adding another specifica-

9| The focus on the social sciences does not restrict the inversion of novelty to this science segment alone. The inversion of novelty also affects the humanities, large areas of medical research and, albeit to a lesser degree, certain areas from the natural and the technical sciences.

10| It is common to specify such concepts on the basis of a theoretical background consisting of various empirical indicators or clusters of indicators.

tion of or a new questionnaire on these two already very diversified theoretical concepts. However, a second-order investigation into the available first-order versions of these two theoretical concepts should produce new insights into the scope and the main domains of standards of living and quality of life, into robust relations between different segments or aspects of standards of living and quality of life or into their mutual dynamics. Additionally, these second-order investigations can be extended to a study on the scope of living conditions and on quality of life combined, which will produce, in all probability, new insights into the differences and similarities between these two concepts (Müller 2013b).

« 22 » *Example 2*: Second-order studies on the analyses of social science data sets reveal a large number of new insights into data utilization patterns, gender-specific preferences in the choice of topics, central and marginal topics in the social sciences and even into the status of empirical social research across different countries. An interesting example is the compilation of a database of articles that used data from the European Social Survey (ESS) from 2003 to 2014. Conducting a second-order ESS study on first-order ESS studies, it became possible to highlight the restricted nature of data utilizations of the ESS, the partial and highly selective amount of actually used time-series data, regions of high and low activities in social research or the very specific interest patterns of European social scientists, with a focus on topics such as social capital or migration and neglecting themes such as intergenerational mobility or religion to a very large extent (Malnar & Müller 2014).

« 23 » *Example 3*: Evaluating a specific ensemble such as a university, an academy of science or a national system of innovation for the *n*-th time will produce, in all probability, less innovative content than a second-order investigation of the *n*−1 evaluation reports so far and their relations to the overall societal dynamics, including political changes (for more details, see Müller 2013d). Moreover, a rich variety of different second-order evaluation designs can be implemented, in principle, so that the outputs of second-order evaluation studies on first-order evaluations are capable of producing significantly higher degrees of novelty than a renewed first-level analysis, given the already available results of previous evaluations.

« 24 » Over time, the accumulation of an increasing number of studies, articles and results in the first-order domain is expected to support the assumption of the inversion of novelty, which is not only limited to the social sciences, but to the science system in general. In turn, this implies that second-order research changes, in due course, from a strange and peripheral issue to a sheer necessity for the contemporary or future global science system as a whole.

Re-entry as the basic operation of second-order science

« 25 » We will now turn to the second-order domain/level and to second-order investigations. 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 domain/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)

« 26 » Similarly, Heinz von Foerster (2003) referred to “understanding understanding,” “communication of communication,” “goals of goals,” “control of control,” etc. These self-applications of first-order science elements accomplish a logical closure because these elements[11] are not only applied in various space-time settings, but also to themselves. Whenever such an element is applied to itself, such as in “understanding understanding,” “science writing of science writing,” or “learning of learning,” the logical realm of applications for these elements becomes closed. In a more formal way, a first-order science building block X with a re-entry operation R produces X(X):

$$X \rightarrow R \rightarrow X(X)$$

« 27 » Aside from the closure of first-order building blocks such as concepts, theories, models, methods, generative mechanisms or scientific fields, these re-entries also constitute a new science domain whose potential has not been sufficiently recognized and has been insufficiently explored so far. What has been mostly disregarded until now is the relevance of these re-entries for the creation or production of new scientific areas of investigation.

« 28 » Using re-entry operations, one can construct a very large number of new research problems and fields for the second-order domain/level. Obviously, these re-entries can be undertaken within all scientific disciplines and sub-disciplines of the first-order domain/level. In general, this vast number of new second-order research problems, challenges and topics is distributed across the same range of scientific disciplines and sub-disciplines that are used for the first-order level/domain. Thus, we would like to put forward a *correspondence principle*, stating that each field at the first-order level/domain has a corresponding counterpart at the second-order level.[12]

« 29 » The correspondence principle can be extended from scientific disciplines to other forms as well that are used in the classification of first order science. Here we want to list five types of corresponding first- and second-order areas.

« 30 » The first type focuses on first-order normative sciences and on re-entries in this domain. Here, second-order investigations are directed to research problems such as a methodology of methodologies,

11 | These are not necessarily only concepts or operations (e.g., “understanding understanding”) but also theories, models and even entire disciplines (e.g., “cybernetics of cybernetics”).

12 | This correspondence principle does not hold between the first-order and the zero-order domain, though. Due to its specific functions, zero-order activities are largely focused on measurements and on ordering, documenting and maintaining available scientific information, which makes it impossible to apply many contexts and dimensions of first-order science to the zero-order domain.

research designs of research designs, a calculus of calculi, an algebra of algebras, rule-systems of rule systems, laws of laws, etc. Usually, these re-entries in normative first-order building blocks generate new topics for second-order investigations and a normative second-order context, which should lead to normative approaches with higher generality, directed towards the foundations of normative sciences.

« 31 » The second type produces re-entries in well-established scientific disciplines and discipline groups such as political science, chemistry or historiography. The social sciences of social sciences can be focused, for example, on social relations between social science disciplines, the environmental sciences of environmental sciences place their emphasis on the environmental relations of environmental science, management science of management science produces second-order management schemes for various traditions of management science, etc. and produces, thus, a new second-order area. Usually, these re-entries into first-order disciplinary domains lead to new and mostly unexplored second-order disciplines, sub-disciplines or, by selecting at least two disciplines, hybrid fields.[13]

« 32 » The third type places the outputs of first-order science at its centre and leads to re-entries into the results, products or, more generally, the available research outputs of a single field or across many disciplines of first-order research. Here, re-entries can be focused on specific causal relations, distributions, tests, patterns, studies, articles, etc. within a first-order field or across clusters of several fields or disciplines.

« 33 » The fourth type is concentrated on the input context of first-order science and generates re-entries such as in theories of theories, models of models, methods of methods and the like. As a concrete example, power-law distributions and their underlying generative mechanisms can be transformed into a second-order study of generative mechanisms of generative mechanisms for power-law distributions. Here, the emphasis changes to a search for more general generative mechanisms that are able to generate different types of generative mechanisms.

« 34 » Finally, the fifth type of re-entries can be focused on the observer-production dimension of first-order science and uses re-entries in the domain of first-order production operations within special disciplines or within the entire landscape of first-order science, i.e., a reflexive shift towards a more general understanding of researchers and their recurrent research operations, including researchers of radical constructivism, systems science or cybernetics and their operations as well.

« 35 » These five types of re-entries for different aspects of first-order science are just a small fraction of the possible re-entries. In general, re-entries can be used to generate new academic fields, new and challenging topics for scientific research or more general second-order building blocks compared with their corresponding first-order counterparts. Moreover, many of these different types of re-entries are expected to be helpful for organizing and conducting new forms of trans-disciplinary research that qualify as post-disciplinary. This extends Erich Jantsch's (1972) classification of multi-, pluri-, inter-, cross- and trans-disciplinary relations and co-operations: post-disciplinary research has to fulfil the following requirements:

a | The inclusion of the entire range of participating disciplines across the natural, medical-technical and social sciences and humanities;

b | The definition of a common reference element such as a theoretical concept, method, model, generative mechanism, theory, a scientific area or sub-area, etc.;

c | The specification of two different levels or domains whereby post-disciplinary investigations are performed at a higher level or at a different domain than the level or domain of theoretical concepts, methods, models, generative mechanisms, theories or scientific areas and sub-areas of the participating scientific disciplines and fields.

« 36 » Many of the challenging new second-order problems require the participation of researchers from different first-order fields or disciplines so that second-order science should provide a big boost for post-disciplinary research designs with a new division of work between the participating researchers or research teams from first- and from second-order science.

The second-order domain, its stratifications and the goals and functions of second-order science

« 37 » In this section we will further focus on second-order science: What significant and vital functions for the science system in general does second-order science provide? What different types of re-entry operations can be constructed? What are the scope and organization of the second-order domain/level and how can they be summarized? How does second-order science differ from first-order science and what are their similarities? And, finally, what is the potential of second-order science, here and now?

Three major functions of second-order science

« 38 » In terms of historical contexts, second-order science can be considered as a collection of research practices that emerged from the 1950s and 1960s at the latest, mostly under the name of "meta-analysis" or occasionally under headings such as "sociology of sociology" (Halsey 2004; Halsey & Runciman 2005; King 2007), "philosophy of philosophy" (Williamson 2007), "historiography of historiography" (Burrow 2009) or "cybernetics of cybernetics" (Mead 1968). But what can be considered the great potential and major functions of second-order investigations in particular and of second-order science in general? Basically, second-order science offers three main functions.

« 39 » The first function of second-order science lies in its role of triggering innovations and inventions, which has been marginally utilized so far. Through re-entries into first-order building blocks such as concepts, theories, models, and mechanisms, a large number of new, highly challenging and mostly unexplored research problems are generated. In other words, second-order science serves as a "novelty pump." Since most topics at the second-order level are largely

13 | Note that even though one might be inclined to think otherwise, psychology of psychology experiments such as Rosenthal (1963) are not examples of the sort of re-entry we envisage here.

unexplored, second-order research becomes a vital innovation engine for science research in general.

« 40 » Novelty or innovation *per se* would not be sufficient to motivate second-order explorations. Second-order studies are able to fulfil two additional vital functions for the sustainability of the science system as a whole.

« 41 » The second function of second-order science is to increase the reliability and robustness of its results compared to their first-order counterparts. Statistical meta-analyses, which in the new terminology become "second-order analyses," point to the possibility of disconfirming or confirming first-order results and of achieving, thus, higher levels of robustness. In other words, second-order science performs the role of quality control for first-order research. Second-order analyses can be very useful for the quality control for research at the first-order level and for producing more robust results and outputs.

« 42 » The third function lies in the integration of first-order elements and in generating higher levels of generality. Similar to the cases of theories of theories, models of models, generative mechanisms of generative mechanisms or methodologies of methodologies, second-order investigations initiate a search and a move towards more general and fundamental forms of theories, models, generative mechanisms and methodologies. In other words, second-order research can lead to more integrative or more general insights into theoretical, modelling and foundational issues.

« 43 » As first-order science advances, second-order science provides three vital functions for first-order science, namely a rich source of novelty and innovation, the necessary quality control and greater integration and generality.

Clusters of re-entries

« 44 » To start with, re-entries into a specific first-order building block X generate a variety of different outcomes so that our original formal description of re-entry needs to

$$X \rightarrow R \rightarrow X\{X_i\},$$

where the set $\{X_i\}$ is composed of an open number of possible second-order solutions that is mostly dependent on the researchers, their levels of cognitive complexity and their imagination.

« 45 » Re-entries into first-order building blocks such as theoretical concepts, models, theories and the like can be pursued in several independent ways and are not confined to a single or unique re-entry solution. This also applies to re-entries in first-order fields or disciplines, as in the case of a sociology of sociology, which can generate several second-order themes or topics that all run under the umbrella term of a sociology of sociology. For example, sociologists as a group or a collective, their operations and interactions can be studied with the tools and frames of sociological research. Likewise, sociology as an academic field with publications and texts can be investigated in terms of their textual network formations such as quotation networks. Finally, sociology as a network of organizations and institutions can be studied in their dynamic network evolution with respect to migration patterns of researchers, co-operations and the like.

« 46 » Thus, re-entries are expected to yield a rich variety of possible outcomes. Moreover, they are strongly dependent on the goals and preferences of the observers who carry out these re-entries.

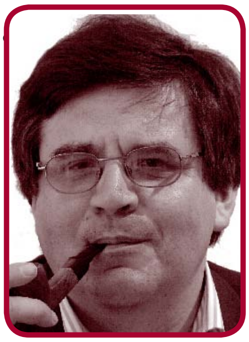
« 47 » Re-entries can be undertaken in several major types and can be grouped into two different clusters.

« 48 » The first cluster is composed of re-entries into a very narrow and specific first-order domain. An obvious and paradigmatic example for the first cluster are re-entries in a specific psychological or a medical drug test where the relevant first-order building blocks are composed of a large number of completed test studies. Under the name of meta-analysis this configuration has become a widely used scientific practice, and a very detailed methodology on meta-analyses has been developed over the last thirty years (see, for example, Borenstein et al. 2009; Hunter & Schmidt 2004; Kulinskaya, Morgenthaler & Staudte 2009). The same applies to other forms of meta-analysis, which are usually focused on a specific topic or on highly specific patterns or relations. The previous result on the multiplicity of re-entry solutions remains unchanged, but the important point here lies in the emphasis of first-order building blocks from a very narrow and special first-order science field, as in the case of specific psychological or medical tests.

« 49 » The second cluster is composed of multiple re-entries into the first-order domain/level in order to create a second-order topic or field of investigation. The second type of multiple re-entries uses building blocks across different areas or disciplines at the first-order level, as in measurements of measurements across many first-order disciplines and fields.

« 50 » Finally, re-entries can be undertaken in the second-order domain as well. At this point an obvious question arises with respect to the possibility and the scope of a third-order level. As a terminological convention, the second-order level in its multi-contextual and multi-dimensional configuration is assumed to be closed in itself and does not give rise to third-, fourth- or higher-order levels or domains. Research outputs at the second-order domain/level can become objects of second-order investigations as well, but this type of research becomes a second-order study of second-order studies. Obviously, the re-entry operation can be re-iterated for second-order studies of second-order studies of second-order studies, etc. Thus, the second-order level allows for the possibility of an open number of layers, where each layer is defined by a specific number of second-order building blocks.

« 51 » In terms of mappings of the second-order level/domain it was already stated that because of the correspondence principle, the mappings of the first-order level/domain can be reproduced for the second-order level/domain as well, albeit with a significant difference. The second-order level/domain, due to the terminological convention of its closure, becomes stratified in an open-ended way. The correspondence principle can be applied to these layers or strata as well. We do not expect, though, that the second-order level/domain will become differentiated into more than two or three of these layers or strata in the foreseeable future since the basic layer of the second-order domain/level has been only explored to a small degree so far.



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Conclusion

« 52 » We conclude our overview of second-order science with a short comment on its relations with radical constructivism on the one hand and with cybernetics on the other hand.

« 53 » Radical constructivism as a research tradition[14] played a strong role in setting the agenda for second-order science. Lou Kauffman, Ranulph Glanville, Bernard Scott and Stuart Umpleby, to name only a few proponents, stressed the importance of reflexivity in research operations. Moreover, second-order cybernetics as a special research program within the radical constructivist tradition provided the conceptual differentiation between first-order and second-order approaches and the categorization of second-order approaches as being inherently reflexive. The move to a general notion of second-order science was undertaken by the authors of this article. Our grand vision of an emergent second-order science was inspired by radical constructivism and second-order cybernetics and would not have been possible without the radical constructivist research tradition.

« 54 » Finally, the differentiation into three levels/domains also brings an exciting new agenda for re-energizing cybernetics (Müller 2014). From the late 1960s onwards, cybernetics appeared in two different perspectives, namely as first-order and second-order cybernetics, where the main difference between these two cybernetic approaches was concentrated on observers and their observations. Adding a second-order domain/level gives rise to a new role or function for cybernetics as a steering and navigation instrument through the waters of first- and second-order science. This type of cybernetics can be labelled as "new cybernetics." It is a unique post-disciplinary research program focussing on two central tasks:

a | New cybernetics assembles, orders and widens the methods, tools and schemes that are used across different second-order science fields.

b | It produces and develops new methods, tools and instruments that enable new types of second-order studies across the full range of scientific fields and sub-fields.

« 55 » Obviously, it will be up to scholars and researchers to decide on the relevance and importance of second-order science and of a new perspective on cybernetics within this context. Nevertheless, in our view a new horizon has been opened up that can be summarized in the following way:

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

14| Research programs within the research tradition of radical constructivism include, to name a few examples, Humberto Maturana and Francisco Varela's (1980) theory of autopoiesis, second-order cybernetics as proposed by Heinz von Foerster (1974), the British approach to second-order or new cybernetics (Pask 2012; Scott 2011; Glanville 2009–2014), Ernst von Glasersfeld's radical constructivism (Glasersfeld 1995) and Stuart Umpleby's program on reflexivity in science (Umpleby 2007, 2010).

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