Chapter 2
Levels of Reality, Complexity, and Approaches to Scientific Method

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Abstract The methodological advances in science are above all associated with enhancing scientific knowledge by means of reliable processes. This requires the analysis of levels of reality, complexity and approaches to scientific method. In this regard, scientific processes can be procedures and methods. The procedures contribute to the initial stages of the inquiry and can complement the rigorous methods. Meanwhile, the methods enlarge our knowledge according to well-established ways or follow research processes whose reliability has been tested.

Scientific research needs methods that deal with objects and problems, whose diversity offers reasons for the unfeasibility of a universal method for science and poses problems for methodological imperialism. The existence of levels of reality (micro, meso, and macro) and the features of complexity, structural and dynamic complexity, pave the way for methodological diversity. Thus, empirical sciences show different approaches to scientific method, such as the differences between natural sciences and social sciences, and also the novelty of the sciences of the artificial in comparison with the social sciences. Consequently, the relations of the scientific methods with the levels of reality and complexity require a deeper view than the conceptions already available.

Keywords Levels of reality · Complexity · Approaches · Scientific method
2.1 The Analysis of Approaches to Scientific Methods

Any approach to scientific method in empirical science deals with systematic ways of increasing scientific knowledge regarding reality — actual or possible — in order to get some kind of progress, which might be a theoretical, empirical or heuristic improvement.\(^1\) Scientific method has more aspects involved than just the advancement of scientific knowledge (mainly, ontological and axiological facets, in addition to the epistemological factors), because science is a human activity geared towards specific goals and developed according to certain values. Nevertheless, the methodological growths in science are above all associated with enhancing scientific knowledge by means of reliable processes. Thus, they are effective — or even efficient — regarding some goals. These processes are related to a reality — natural, social or artificial — that has different levels and, very often, includes complexity.\(^2\)

Accordingly, the analysis of the approaches to scientific methods can consider at least three kinds of aspects — epistemological, ontological and axiological — that can be related to the assumptions, contents or limits of methods in science. (a) There are some assumptions in scientific methods, which are connected to ontological issues (such as micro, meso or macro levels of reality or the intelligibility of phenomena\(^3\)), to epistemological factors (such as cognitive rationality), and to axiological considerations (the kind of values — internal and external — preferred to choose ends and means of research). (b) The contents require cognitive rationality, while the processes themselves can be analyzed in connection with the practical rationality (or even with a possible logical basis shared by the processes) and the role of historicity.\(^4\) The main values involved are efficacy and efficiency in problem-solving. The analysis of these processes can lead to a distinction between procedures and methods. (c) Any scientific method can have limits in two directions: in terms of a barrier, insofar as there should be some kind of frontier between a method that is scientific and another that is not, and in terms of confine, because there should

\(^{1}\)On the present views on how to characterize “heuristic,” see Chow (2015).

\(^{2}\)This presupposes that there is a connection between methodology of science and ontology of science, which certainly has a close relationship with epistemology. In this regard, it is important to emphasize that the ontology of science is not something merely defended from perspectives of scientific realism but also from other philosophical positions, including anti-realist viewpoints. Thus, “even strongly empiricist approaches advocate a conception of scientific ontology: an ontology of observable objects, events, processes, and properties” (Chakravartty 2017, 41; see also 59–60 and 63).

\(^{3}\)In this regard, it seems odd to claim that “the epithet ‘intelligible’ applies to theories, not to phenomena” (de Regt 2017, 12; see also pp. 45 and 88).

\(^{4}\)Some of the conceptions in favor of monism, reductionism and methodological universalism, especially those of a directly logical-methodological kind, do not pay attention to historicity. But historicity is a key factor in understanding scientific change, complexity and problems related to scientific prediction, cf. Gonzalez, W. J. (2015b, 25, 29, 56n, 62, 77–78, 91, 103, 133, 185, 222–223, 249, 257, 267, 279n, 308 and 310).
be a ceiling for the method used (i.e., a realm where the method is actually valid) (Gonzalez 2016).

Altogether, this set of aspects configures the environment where the analysis of levels of reality, complexity and approaches to scientific method is located. In addition to these three features, there is a fourth one that accompanies them: the analysis needs to consider that there is a use of methods in accordance with the kind of research. Thus, there might be methodological differences between the research made in basic science, in applied science, and in the application of science. Moreover, there might be distinctions between the methods in the cases of natural sciences, social sciences, and the sciences of the artificial.

### 2.1.1 The Acceptance of Processes for Scientific Method: An Internal and an External Side

First of all, there is acceptance of processes in the approaches to scientific method, which includes an internal and an external side. From an internal viewpoint, these processes in science might be considered from different philosophical angles (universalist, pluralist, imperialist, convergent, selective, etc.), which are assigned by the methodological approaches. But the processes that lead to scientific progress cannot be reduced to theoretical and empirical components, because heuristic aspects really matter if we want to grasp sciences such as psychology or economics.

From an external viewpoint, the approaches to scientific method can have an impact on the contexts where science has a relevant role, because science has a clear repercussion in contemporary society (in individuals, groups, organizations, nations, etc.), as the current research on Covid-19 patently illustrates. In addition, these approaches can have consequences for technological innovations (Gonzalez 2005), which can also lead to social innovation (as is the case with the sciences of the Internet and the electronic commerce) (Gonzalez 2020c).

Meanwhile the meta-methodological considerations take into account the existence of a reality, actual or possible, to be researched with the methods. In addition,

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5Cognitive rationality with practical rationality and evaluative rationality are the three main spheres of rational deliberation, cf. Rescher (1988, 2–3). These three spheres of rationality may be intertwined in science. Moreover, this epistemic, practical and evaluative intertwining can be seen in the current efforts to find an effective treatment for Covid-19 patients and an adequate vaccine to avoid future problems. For pragmatism, they involve three ranges of philosophical concern, cf. Rescher (2019, 58).

6On the characterization of the sciences of the artificial, see Simon (1996).

7Convergent and selective prospects for methodology of science have been discussed in conceptions related to scientific realism. On these views, see Gonzalez (2020a).

8Regarding psychology, see for example Gigerenzer and Gaissmaier (2011).

9In the case of economics, this is particularly clear. See Gonzalez (2014).
the increase in scientific knowledge by means of reliable processes should have a clear support. Thus, either the processes are consistent in logical terms, or, at least, these processes are based on a neat rationality (i.e., a scientific rationality that includes historicity). Commonly, the meta-methodological considerations assume that the whole set of elements involved with the scientific processes (theorizing, modeling, hypothesizing, representing, etc.) follow some kind of implicit or explicit rules, which are based on rational grounds (or even because they have some kind of logical basis).

2.1.2 A Framework of Processes: Procedures and Methods

These processes used in scientific research are at least twofold: procedures and methods. (a) “Procedures” are those processes that contribute to the initial stages of the inquiry (such as the processes for judgmental predictions) and can complement the rigorous methods (especially for qualitative factors). They might become genuine scientific methods in the future. Meanwhile, (b) the processes are already scientific “methods” when they enlarge our knowledge according to well established ways or follow research processes that have been tested for their reliability.

But both kinds of processes used in science — procedures and methods — deal with an ontological basis — the levels of reality that configure the object studied — and they build upon the epistemological factors (in basic science, in applied science or in the application of science). Furthermore, they assume certain internal and external values, insofar as the ends and means of the processes of scientific research are chosen in accordance with certain values, which may be cognitive, social, etc.

This difference regarding the type of process is particularly clear in the case of scientific prediction. We can distinguish two types of processes: (i) predictive procedures (i.e., informal or less sophisticated ways of searching), and (ii) methods of prediction (or “predictive methods” according to a more rigorous path). Both types of processes are used de facto in the daily practice of sciences such as economics. They can be employed independently or, as is more common, in a combined form. Moreover, the use of judgmental and scientific approaches is

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10 The search for a logical basis for methodological approaches is possible in the sense proposed by John Worrall. See Worrall (1988, 1989b, 1998).
11 Scientific rationality should include historicity insofar as science is a human activity embedded by historicity in several ways. See Gonzalez (2011b, 2012c).
12 On the difference between “procedures” and “methods” in science, which is noticeable in the case of scientific prediction, see Gonzalez (2015b, 255–273). On the setting of methodological options for scientific prediction, see Rescher (1998a, 85–112).
13 These values play a role in preferring a type of methodological conception (pragmatic, pluralist, instrumentalist, etc.), but they also influence the configuration of the kind of social impact considered, which can be realistic, relativistic, constructivist, etc.
explicitly assumed in econometrics.\textsuperscript{14} Indeed, in addition to the contribution of the economists, the role of non-specialists is sometimes accepted for adjustments.\textsuperscript{15}

Among the reasons for using procedures and methods — and an explanation for the daily presence of both types of processes for prediction in science — is their need in solving problems related to complexity, mainly dynamic complexity. The advancement of science in any of these three cases of scientific research — basic, applied or of application — commonly requires dealing with complex systems (natural, social or artificial), which might be at least epistemological as well as ontological (Rescher 1998b, 9).

Moreover, this dual complexity can be structural and dynamic, which are two different aspects that are particularly relevant for scientific methods, as is seen in sciences such as biology (Gonzalez 2015c) and economics (Gonzalez 2011a, 2013b). Furthermore, the structural and the dynamic versions of complexity are open to a diversity of possibilities, according to the levels of reality (micro, meso and macro) and because of the variations of the temporal factors (in the case of prediction, there will be at least short, middle or long run).

2.2 Methods, Objects, and Problems

Initially, scientific methods are focused on two key factors: a type of object, either formal or empirical (i.e., natural, social or artificial), and a sort of problem — possible or actual — related to the object to be researched. In this regard, each approach to scientific method commonly requires one to take into account the level of reality studied (micro, meso, or macro) and within the temporal framework (past, present or future), which can include additional traits (such as short, middle or long run). In addition, the kind of complexity present in the research objects must very often be considered in problem-solving.

\textsuperscript{14}“There are numerous ways of generating economic forecasts. Many are a mix of science — based on rigorously tested econometric systems — and judgment, occasioned by unexpected events: the future is not always like the present or the past” (Hendry and Ericsson 2001, 186).

\textsuperscript{15}“Although progress is being made, we are still some way from a position where the model answers can be accepted without further human intervention. This is standard international practice. McNees surveyed the large U.S. forecasting organizations in 1981; they attributed between 20 and 50% of the final forecast to judgmental adjustments (\ldots). Adjustments are made in the light of other information, commonsense judgements, past model error, and a knowledge of its deficiencies. The useful exercise of this judgement is not limited to the specialists. Non-specialists may also make a valuable contribution providing that the issues are put to them clearly” (Burns 1986, 104).
2.2.1 Complexity of the Objects to Be Studied and Perspectives for Research

Usually, the complexity of the objects to be researched can be studied in three ways: (a) in epistemological or ontological terms, (b) in its structural or dynamic varieties, and (c) its internal or external domains. Following the type of object and the sort of problem, the research is led to a scope (i.e., a grade of generality in the problem to be studied, which varies from general to local) and which requires a style of research in tune with it. Thus, the research commonly takes the features of the accepted methods, or it proposes new methods to increase our knowledge, either of abstract forms (formal sciences) or of a possible or actual reality (empirical sciences).

Consequently, a scientific method can be oriented to any of the three main scientific ambits: (1) basic science, where the focus is mainly theoretical, which leads to explanations or predictions; (2) applied science, where there is mostly a practical research, which includes predictions and prescriptions; and (3) application of science, which is that used by the agents of the scientific knowledge according to contexts (this contextual usage requires, in principle, the previous step of applied research but, at the same time, it can reinforce the research of applied science).

Furthermore, the scientific methods can focus on the sort of problem to be researched from several possible perspectives. These may be commonly within five main cases: (i) that of “just” a discipline (such as physics, biology, economics, sociology, pharmacology, communication, etc.), (ii) that of an interdisciplinary field (such as biochemistry, psychophysiology, psychopedagogy, etc.), (iii) that of a multidisciplinary endeavor (e.g., the studies of several sciences on the characteristics of a region or state), (iv) that of a crossdisciplinary task (such as conservation genetics), or (v) that of a transdisciplinary province (such as gender studies).

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16 For complex systems, it is feasible to have a kind of methodological pluralism in terms of “having different models for different features of a phenomenon” (Morrison 2015, 7). But this involves the polyhedral character of the reality studied, whether natural, social or artificial.

17 Obviously, “the abstract nature of mathematics can nevertheless yield concrete physical information” (Morrison 2015, 4).

18 On the need for the distinction between applied science and application of science, see Niiniluoto (1993, 1–21; especially, 9 and 19). On the differences between basic science, applied science and application of science, see Gonzalez (2013a, 11–40; especially, 17–18).

19 See monographic issue on “Philosophy of Interdisciplinarity,” (2016). European Journal for Philosophy of Science, 6(3). It includes the paper by Knuutila and Loettgers (2016). See also Niiniluoto (2020).

20 Crossdisciplinarity is characterized by problems that are discussed using methodologies that, in principle, come from disciplines that are not thematically related. This is the case with a discipline at the micro level, such as genetics, and one at the macro level, such as environmental science, which intersect in the conservation genetics. Thus, thematic barriers are crossed in crossdisciplinarity, but not in principle methodologies. Meanwhile, methodologies are combined in interdisciplinarity, because a common point of encounter is sought from different starting points.
But the research object might be more complex than in previous decades, insofar as the intervention of technology is more intense, as in the case of the sciences of the artificial that deal with the development of the Internet as a network of networks (cf. Gonzalez 2018a), where the communication and information technologies (ICT) have a crucial role in developing new aspects related to Artificial Intelligence (AI), such as “deep learning.” This relation of scientific creativity and technological innovation can lead to new objects, novel problems, and scopes with no precedents, as happens with the research on AI and the development of computer sciences (Gonzalez 2017).

Another way to increase the complexity of the research object is emergence, which is related to the novelty, at least in two characteristic features. First, “there is some aspect of the emergent entity that is novel” (Humphreys 2016, 5), i.e., a characteristic that is autonomous regarding those components from which it is developed. Second, there is some holism, insofar as there is at least one fact that, related to the new aspect, is not previously in what already exists and the rules that regulate it. Thus, emergence adds something to the set where the new appears (cf. Humphreys 2016, 5).

Methodologically, the emergence often has a transdisciplinary component, because emergence might be in a number of disciplines (physics, chemistry, biology, economics, sociology, etc.) that can be interrelated to give rise to something new within a certain set. Ontologically, emergence can be at any level of reality (micro, meso, macro) and can be found, in principle, in the natural, social and artificial realms. In the natural sphere, it commonly goes in two main directions: (a) transformational emergence (cf. Humphreys 2016, 60–69) and (b) fusion emergence (cf. Humphreys 2016, 70–86). In this regard, it is generally assumed that emergence occurs in an ‘upward’ direction, although Paul Humphries considers that “this is not inevitable” (Humphreys, 80).

Besides the level of reality studied (micro, meso, or macro) and its complexity, scientific objects depend on the temporal scale of the phenomena (natural, social or artificial), where the short, middle or long run can be relevant. This is the case in basic science with explanations — especially if we work with retro-dictions — and in predictions (see, for example, Worrall 1989a). If we look backwards, then functional and genetic explanations combine the level of reality and the temporal scale in order to answer “why” questions (e.g., in biology or in demography). If we look forward, then foresights, predictions and forecasts require a specification

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21 This kind of science deals with designs and is different from the social sciences, even though there might be dual sciences — artificial and social — as happens with communication sciences, cf. Gonzalez (2008b).

22 This downward or descendent approach seems odd, insofar as it suggests the ideas of immersion, submersion or submergence.
of the level of reality of the phenomena and temporal scale (which can include the immediate and the very long term).23

When the focus is on applied science, then levels of reality and temporal scales affect the relations between prediction and prescription, which are the main elements in modeling applied research (Simon ([1990] 1997). It seems clear that applied science requires solutions to concrete problems (Niiniluoto 1993, 1–21; especially, 2–3 and 5–6; and Niiniluoto 1995), where ontological factors are certainly important and are a condition for epistemological and methodological components. In addition, values have a role in order to choose what prescriptions should guide the solution of the concrete problems (as is seen in the case of economics) (Gonzalez 1998).

Also, application of science depends on the levels of reality. The ongoing debate on climate change has a very important component of the application of the scientific knowledge available, which includes a large set of predictions and a number of prescriptions to be implemented at the three levels: micro, meso, and macro. Thus, while some prescriptions can be implemented by individuals and small groups, others are to be carried out by organizations such as business firms and corporations, and there are also world-wide patterns of action that belong to the United Nations organization and the countries that signed the Paris agreement on 12 December 2015 (United Nations 2015).

2.2.2 Unfeasibility of Universal Method for Science

While doing research on this complex set of objects from quite different perspectives and on diverse levels of reality, we use a plurality of methods. That is why, although there might be a search for some central features shared by all the scientific methods used so far (and even those that might be used in an immediate future), there is no universal method that might be used in all the scientific areas.24 Thus, formal and empirical sciences have differences regarding the type of problems, the kind of models (either descriptive or prescriptive)25 and the characteristics of the results. In addition, the empirical sciences (natural, social and artificial) have methodological differences. This is also the case within the sciences themselves (physics, biology,

23 Cf. Gonzalez (2015b, v, vii-viii, 2, 4, 6, 10n-11, 13, 18–21, 25, 30, 32–40, 47, 56, 60, 64, 69, 71, 77, 93, 114, 127, 129, 140, 150–151, 159, 165, 173, 184, 215–216, 218, 221, 249–250, 254–256, 264, 272, 275, 277–278, 288–289, 304, 308, 317–322, and 324–338).
24 Cf. Gonzalez (2012a). The analysis made in this section and the next one is based on this paper.
25 Descriptive models are characteristic of basic science, whereas prescriptive models are used in applied science.
economics, etc.), where there are methodological variations according to the level of reality studied (micro, meso and macro) and the problems addressed.26

Nonetheless, we can consider that there are varieties of methodological universalism. A key element is the extent of the scope, which allows several levels of methodological analysis. In principle, there are three main ranks of scientific research: (1) science in general (mainly, the empirical sciences)27; (2) a group of sciences, such as the natural sciences, the social sciences, or the sciences of the artificial; and (3) specific sciences, such as biology, economics, or computer sciences. These ranks embrace the diverse options of a methodological universalism in scientific research:

(a) Methodological universalism regarding science in general is now commonly considered problematic due, among other reasons, to the structural and dynamic complexity (Gonzalez 2020b). Thus, methodological proposals valid in principle for all empirical sciences, such as those of logical empiricism, are no longer accepted.
(b) Another view is that of a methodological universalism in a group of sciences, as has happened in the social sciences, which has led to a version of methodological imperialism (based on economic imperialism).
(c) There might be the view of a sort of methodological universalism located within the specific sciences (biology, economics, computer sciences, etc.).

Actually, we can see this version of universalism in disciplines of the natural sciences, such as biology (which is largely influenced by processes understood in evolutionary terms, frequently Darwinian); in subjects of the social sciences, such as economics (where the methods of mainstream economics — sometimes called “orthodox” economics — are still extremely influential both in theoretical and practical terms); and in studies of the sciences of the artificial, particularly in sciences of design developed in the sphere of computer sciences working with Artificial Intelligence.

What makes any sort of methodological universalism quite difficult is complexity. Certainly, organized complexity — and, even more, disorganized complexity — is a very important source of difficulties for methodological universalism. It can affect problems, methods and results of the scientific research. The features of complexity can be thought of as science, in general, a group of sciences, or a specific science, because complexity can be considered, in principle, by any of the disciplines related to nature, social and artificial worlds (see, in this regard, Mainzer 2007). To some extent, we can consider complex systems in these main spheres of the reality.28

26This feature of diversity is especially highlighted by methodological pluralism, but is also indicated by methodological pragmatism, when it connects the various goals sought with effectiveness in the research process. Cf. Gonzalez (2020e).
27Formal sciences, such as mathematics, commonly have specific methodological considerations, even though “quasi-empiricist” approaches and naturalist conceptions have searched for methodological similarities with empirical sciences.
28In addition, the degree of complexity matters, especially for modeling. Thus, in the case of computer simulation, “the system can be modelled at various levels of complexity, ranging from very simple models that don’t include any interactions to more complicated modelling that
Complex systems can be focused either from the structural or the dynamic variety. Both varieties involve the possibility of emergent properties. In the first case, the study of complexity is commonly made regarding the framework or constitutive elements present in a group of sciences or in a specific science. Meanwhile, in the second — the dynamic version — addresses internal and external variations. In the dynamic case, the analysis of complexity is related to change over time of the motley elements involved in that collection of sciences or the specific science, taking into account the forces generating the change.

2.2.2.1 Difficulties Based on Structural Complexity: Epistemological and Ontological

It seems clear that obstacles to methodological universalism can be located on both sides: in structural complexity and in dynamic complexity. Concerning the structural case, we consider the main epistemological and ontological aspects. Nicholas Rescher has made a relevant presentation (see, in this regard, Rescher 1998b, 9), where the *epistemic modes* of complexity are divided in three groups, in which it is possible to find a formulaic complexity: (i) descriptive complexity; (ii) generative complexity; and (iii) computational complexity.

Each presents epistemological difficulties for a universal method. De facto, they make it more difficult to characterize the advancement of scientific knowledge that validly grasps how the finding and evaluation of science itself is, a group of sciences or a particular science. The difficulties can be in the three formulaic cases mentioned: (a) there might be complications in providing an adequate description of the complex system addressed; (b) there can be obstacles in providing the keys by which the system studied has been generated; and (c) there might be relevant issues of time and energy involved in solving the problems that such a complex system poses.

We can find *descriptive complexity* in each tier, if we accept that the configuration of science includes macro-theoretical frameworks, theories, models, hypotheses and processes for evaluation (observation, experimentation, ...). This difficulty of descriptive complexity increases when the object to be studied is macro and as broad as the biosphere, in the case of biology, or the infosphere, in the case of the sciences of the artificial. Meanwhile, *generative complexity* can be at the

encompasses physics and engineering models, with the more complicated type giving rise to a greater probability errors” (Morrison 2015, 272–273).

29 On complexity from a *dynamic point of view*, see Gonzalez (2013b).

30 “The prospects for the emergence of an effective complex system are much greater if it has a nearly-decomposable architecture” (Simon 2001, 82).

31 These categories of structural and dynamic can be used to articulate lists of kinds of complexity such as “multilevel organization, multicomponent causal interactions, plasticity in relation to context variation, and evolved contingency,” Mitchell (2009, 21).

32 On infosphere see Floridi (2014).
macro level (e.g., the cosmology around the big bang and the next steps), at the meso level (e.g., how certain epidemics are generated), and at the micro level (e.g., how social decline is generated in certain areas, according to the type of dominant industry). *Computational complexity* is characteristic of far-reaching and wide-ranging problems, whether spatial or temporal. This is the case for some astrophysical questions or issues related to climate change. But it can also occur when treating other problems, such as those related to the functioning of the human brain or issues regarding the human genome.

Even greater difficulties for the universal method come from the *ontological modes* of complexity. These are also distributed in three main groups: (1) compositional complexity; (2) structural complexity (in a strict sense); and (3) functional complexity. Within the compositional complexity, the possibilities are twofold: constitutional and taxonomical (or heterogeneity). Meanwhile, for Rescher, “structural complexity” also has two possibilities: it includes organizational and hierarchical complexities; whereas functional complexity is articulated into two modes: operational and nomic.

These ontological obstacles to a universal method can be in any type of reality (natural, social or artificial) and at any level (micro, meso or macro). Initially, there is the *complexity of composition*. One of the typical features of a complex system is that “the system cannot be fully understood by analysis into its components” (Humphreys 2016, 262). Thus, a biological ecosystem or an international social or economic organization is not reduced to its component parts. Constitutional complexity depends first on its components or constituent elements. Then there is a heterogeneity of elements, which expresses a taxonomical complexity in terms of the variety that can exist, for example, in a biological ecosystem or an international social or economic organization.

Thus, the *structural complexity* (in a strict sense) is also a source of obstacles. Organizational complexity can show many possible ways of arranging components, because they can be in different modes of interrelation (as the interdisciplinarity, transdisciplinarity or crossdisciplinarity make explicit). Even when there is hierarchical complexity, the possible relationship of subordination in terms of inclusion and subsumption can be questioned, as it happens nowadays with the criticism of the “fundamental” science. This is a problematic issue for some disciplines, which have traditionally worked with a part considered to be the bedrock of the discipline’s architecture or that served as a general support for that branch of knowledge as a whole (physics, chemistry, biology, etc.).

*Functional complexity* can reveal varieties of modes of operation, which is one of the causes of concern in biomedicine and pharmacology. This is of particular concern for investigating viral pandemics such as Covid-19. In addition, the possible laws — if there are any in the phenomena studied — can be intricate. This is a particularly sensitive issue in the social sciences, where the question arises as to whether, first, “laws” fit in and, second, whether they are “laws of” or “laws in”. When it comes to “laws of”, it is considered that they are something that regulates the complex system under consideration (such as laws of the economy, like laws of the markets, etc., or laws of history, whether they are deterministic or not, etc.).
Whereas, if they are “laws in”, then they are regularities or patterns found after a thorough analysis of a complex social system (such as the laws of economic transactions or the laws of demography).

2.2.2.2 Additional Difficulties: Dynamic Complexity Based on Historicity

In addition to structural complexity as a source of difficulties for methodological universalism, there is dynamic complexity, which brings with it the difficulties related to scientific change over time. Rescher’s analysis is mainly related to structural complexity (the complex framework of the elements of science). He pays little attention to dynamic complexity (that connected to scientific change). Nevertheless, he is open to some dynamic aspects, which are relevant for science, in general, a group of sciences or a specific science. These dynamic aspects might be detected in the generative complexity (in the epistemic modes of complexity) and in the operational complexity as well as in nomic complexity (in the ontological modes of complexity).

Obviously, each mode of structural complexity — epistemic or ontological — can pose some difficulty for the universal methodology, regarding generality and reliability. But this difficulty increases when the dynamic complexity — due to changes through time — intervenes, which certainly modifies concepts — on the epistemological level — and which also generates ontological novelty (the emergence of a new property, of a different process, etc.). Throughout history of science this has sometimes translated into conceptual changes: the incorporation of new concepts, the change of sense of others already existing, . . . and, when the variation is deep, we have conceptual revolutions (Thagard 1992).

Historically, it happens that the methodology of science needs to deal with issues that are not simple, which might be at different epistemological levels and can belong to diverse stages of reality. The researcher uses processes that depend on the objects (the aspect of reality studied) and the kind of problem (the focus of attention). In this regard, insofar as the scope of research is larger, the validity of the contents can, in principle, decrease due to the problems of testing the hypotheses. This can often be seen in economics, where dynamic complexity usually accompanies structural complexity (as evidenced by the previous international economic crisis and already seen with the current crisis due to Covid-19).

If we think of a science such as economics, the sources of structural complexity resemble a scale with several steps: (i) the social and artificial realms; (ii) the micro, meso, and macro levels; (iii) the degree of autonomy as human undertaking (“economic activity” and “economics as activity”); (iv) the organizations (big corporations, medium enterprises, small business firms, etc.) and markets (international,
national, regional, and local); (v) the role of groups and individual agents (i.e. creativity in different realms); … 33

Along with the multiscale structural complexity there is the dynamic complexity. When this happens (e.g., in economics), historicity has a key role and is another obstacle for methodological universalism. The change introduced by historicity — in knowledge and in reality — makes it more difficult to get universality across historical periods. This affects all kinds of objects of research: natural happenings, social events or contributions in the artificial world. Dynamic complexity also makes it difficult for there to be, for a long time, a dominant universalism in science itself, in a group of sciences or in a particular science. This is what happens if one accepts the existence of scientific revolutions, understood as profound changes in concepts, scientific practices and institutional approaches in research centers.

Through dynamic complexity there are then serious obstacles to two types of methodological universalisms. First, there are obvious obstacles for a methodological universalism conceived in a somehow “timeless” format, where the universality of the methodology is accepted across times. In this regard, dynamic complexity goes in the opposite direction to the conception that the scientific method can just be enlarged but not revised in any strong sense (e.g., the dominant view of logical positivism in the early stages of the Vienna Circle). Second, the dynamic complexity also makes it difficult for a temporal methodological universalism to last, when an approach is assumed as dominant during a historical period (e.g., what has happened in physics regarding methods used in mechanics in certain historical periods) (Gonzalez 2012a, pp. 159–161).

Certainly, a dynamic in terms of evolution (e.g., in the study of certain complex biological systems) is not the same as a dynamic conceived in terms of scientific revolution (e.g., in the transition from Newtonian to Einsteinian cosmology). But from the characteristics of historicity it is possible to encompass both “evolution” and “revolution” in science (Gonzalez 2011b). Also, as highlighted later, the historicity has a role in the internal dynamics in each of the steps of the scale indicated, so that it can be given in the realms, levels, types of activity, entities, agents (individuals or groups), … In turn, historicity has a role in the external dynamics, since each of the steps of the scale has relations with the environment, whether natural, social or artificial. 34

2.2.3 Problems for Methodological Imperialism

Another antagonist of the methodological diversity in science is the view of methodological imperialism. There is methodological imperialism in at least two

33 The analysis of these elements is made in Gonzalez (2015b, especially chapter 7, 171–199), where there are more details about these issues.

34 In the case of the sciences of the artificial, the dynamics is analyzed in Gonzalez (2013b).
different ways: intensity within a realm and extension to other realms. Thus, (I) methodological imperialism can be conceived of in terms of a kind of neat
prevalence or clear dominion of some methods regarding a certain scientific realm
(such as happened historically with Newtonian mechanics within physics as a
whole); and (II) methodological imperialism can be understood as a set of methods
that come from a different discipline, whose “boundaries” overflow to impinge
on another field or fields (e.g., economic methods used in sociology, psychology,
anthropology, law, political science, archeology, etc.). This predominance could be
the case in any of these three levels of methodological analysis.

Again, there are several possibilities. Thus, methodological imperialism can be
thought of as science in general, for example, developing a methodological proposal
based on logical grounds and assuming the idea of universal validity of logic. But
it is also possible to think of a methodological imperialism of a naturalist kind,
which might be based, for example, on evolutionary grounds, such as the influential
Darwinian approach (Gonzalez 2008c). Its repercussion is very noticeable in natural
sciences, such as biology; in social sciences, such as in the evolutionary conceptions
of psychology and economics (Nelson and Winter 1982; Hodgson 1993, 1995, 1999,
2001, 2004); and in the sciences of the artificial, such as computer sciences in terms
of evolution of a complex system (Simon 1996, 188–190).

As a matter of fact, the attempt at a “methodological imperialism” has been made
explicitly in the social sciences, while using economic methodology for solving
very relevant social problems. This proposal for studying phenomena of a group
of sciences has usually been connected to the work of a Nobel Prize winner in
economics, Gary Becker, a central figure of the Chicago school. Nonetheless,
from a historical point of view, there are other authors that have been considered
as supporters of an imperialism of economic roots. Becker has tried to solve
important social problems (e.g., those regarding family matters, such as marriages,
divorses and fertility) by means of economic methods (based on neoclassical
models).

Economic imperialism, which is a form of economic expansionism, is a kind
of methodological universalism that fits quite well into the influential tradition of
“economic imperialism” defended at least by economists of the Chicago school.
This view was accepted by George Stigler, who saw economics as an imperial
science, insofar as “it has been aggressive in addressing central problems in a
considerable number of neighboring social disciplines, and without any invitations”
(Stigler 1984, 311).

35His view is analyzed in Pies and Leschke (1998). On methodological imperialism from a
Popperian perspective, see Radnitzky and Bernholz (1987).
36This is the perspective that deals with domains of phenomena that previously were not generally
perceived as “economic,” but are now analyzed in economic terms. See Mäki (2009, 352).
37Among his most influential works are Becker (1976, 1981). On his views, see Cabrillo (1996).
Regarding this topic, cf. Stigler (1984).
For Stigler, this noticeable influence of economics on other fields can be seen in four territories: law, history, social structure and behavior, and politics. Thus, methodological imperialism can be seen in at least in a number of cases: (1) the economics of law, with the application of economic analysis to legal rules and legal institutions, is in Ronald Coase and Richard Posner; (2) the new history made in economic terms is in Robert Fogel; (3) the economics analysis of social structure and behavior (crime, racial discrimination, divorce, etc.) is developed by Gary Becker; and (4) the economic analysis of politics, for example of constitutional design, is used by James Buchanan and Gordon Tullock, the founders of the “Public Choice” school. In all of them, the repercussion of economics is on a relevant scale and with a large number of specialists.

Undoubtedly, the problems posed by complexity in their several facets — epistemological and ontological, structural and dynamic, internal and external — involve the existence of important methodological limits for this tradition of “economic imperialism.” These have a direct repercussion on what methodological imperialism can actually achieve and lead to a methodological diversity in this group of sciences. But this diversity is open to a possible convergence in the methodological components of scientific research. In this regard, the analysis of methodological diversity might show something that is shared by the diversity of methods used in science (natural, social, or the artificial).

2.3 Levels of Reality and Complexity

One way to address methodological problems is in holistic terms, another is to deal with them according to levels of reality research. Prima facie, a methodological holism in science based on an ontological view without levels of reality has many problems, even in the case of physics. De facto, in the sphere of mechanics, physics distinguishes models that work well at the micro level of the atom (quantum mechanics), in the meso level of phenomena of movements on Earth (Newton’s

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38On Fogel — Nobel Prize winner in 1993 — and the methodology of the “new history,” see Gonzalez (1996, 25–111; especially, 29, 37, 74–75, 86, 90–91, 95, 105, and 107).

39Buchanan was awarded the Nobel Prize in economics in 1986. Regarding his methodological views, and in particular his approach to prediction in economics, see Gonzalez (2006a, 89–90 and 100–101).

40On the internal and external complexity, see Gonzalez (2012b).

41The analysis of the relationship between economics and the Internet shows that it is a multivariate relationship. Thus, there are nuances in the role of economics depending on whether it is the scientific side, the technological facet or the social dimension of the network of networks. Cf. Gonzalez (2019).

42In the case of the sciences of the artificial related to the Internet, a common feature is the interdisciplinarity. See Tiropanis et al. (2015), Berners-Lee et al. (2006), and Hendler and Hall (2016).
fundamental laws) and in the macro level of the universe (Einstein’s theory of relativity). Thus, a methodological approach needs to be aware of the role of the properties and processes that science grasps within our system of knowledge — properties and processes that are related to levels of reality.

2.3.1 Within the Levels of Reality: Properties and Processes

Methodological holism looks first at the studied whole and, within that whole, attends to its parts. Meanwhile, the levels of micro, meso and macro reality raise the possibility of differentiated properties and processes according to levels of reality (micro, meso and macro) and ontological realms (natural, social or artificial). In this respect, when investigating complex systems, we have the following:

(a) In many real world cases, “the whole is more than the sum of the parts,” as Herbert Simon insisted for complex systems such as economics. This possibility is also valid for natural phenomena (e.g. biological organisms are more than the sum of their components) or even for complex artifacts (like in the case of the Internet, which with the Web and the cloud computing, works as a network of networks organized as a complex system with layers) (Clark 2018; Gonzalez and Arrojo 2019).

(b) There are “topological” properties, insofar as there are features of natural, social or artificial systems that appear only at a level of reality but are not available at other levels of the real world. In this regard, the laureates of the Nobel Prize in Physics 2016 have opened “the door on an unknown world where matter can assume strange states. They have used advanced mathematical methods to study unusual phases, or states, of matter, such as superconductors, superfluids or thin magnetic films. Thanks to their pioneering work, the hunt is now on for new and exotic phases of matter. Many people are hopeful of future applications in both materials science and electronics.”

(c) Complex systems are not commonly “isolated” structures but rather a type of structure interconnected with other structures of a different kind (as happens with

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43 Simon (1996, 184). In economics the complexity of the structures can originate emergent properties: Schenk (2006).

44 The Royal Swedish Academy of Sciences, The Nobel Prize in Physics 2016, https://www.nobelprize.org/nobel_prizes/physics/laureates/2016/press.html (accessed on 1.12.2016). “The three Laureates’ use of topological concepts in physics was decisive for their discoveries. Topology is a branch of mathematics that describes properties that only change step-wise. Using topology as a tool, they were able to astound the experts. (...) We now know of many topological phases, not only in thin layers and threads, but also in ordinary three-dimensional materials. Over the last decade, this area has boosted frontline research in condensed matter physics, not least because of the hope that topological materials could be used in new generations of electronics and superconductors, or in future quantum computers. Current research is revealing the secrets of matter in the exotic worlds discovered by this year’s Nobel Laureates.” The Royal Swedish Academy of Sciences (2016).
the physical properties connected to chemical properties, physical properties associated to biological properties or physiological elements related to psychological components). According to Humphries, “most sciences use a mixture of properties from other sciences” (Humphreys 2016, 126). What seems clear is that there might be properties of different kinds and that “multiscale modeling is common in areas such as climate modeling” (Humphreys 2016, 126).

(d) Complex systems can introduce new properties through changes over time. This kind of emergence may occur at the micro, meso or macro level, as happens in economics or in physics. These emergent properties are due to internal and external variations over time. In this regard, it does not contribute much to the characterization of the variation introduced by the change over time to indicate that “it is an essential feature of emergence that the emergent entity emerge[s] from something else” (Humphreys 2016, 160).

Among the levels of reality, such as micro and macro, there might be interesting phenomena. Because “various kinds of materiality different systems such as magnets, fluids and gases having different kinds of micro-properties nevertheless exhibit the same kind of macro-behaviour when they reach their critical point” (Knuuttila and Loettgers 2016, 380). The existence of this kind of phenomena raises the issue of the relations between the levels of reality, which are three — micro, meso, and macro — instead of just two, because the properties at the low level might not be actually relevant for the high level (which happens with aggregate macroeconomic events in comparison with the microeconomic events) or even for the meso level. Meanwhile diverse phenomena at one of the levels can share some common properties even though they have different origins (which explains the use of evolutionism for the analysis of economic and sociological events).

2.3.2 Micro, Meso, and Macro as Ontological Levels for Complexity

Ontological levels of reality are relevant for methodological discussions. Thus, because of the interrelation between methods and objects of research, when science is dealing with methodological problems, the possible epistemological advancement depends on ontological support. This leads to different kinds of methods, insofar as a scientific method needs to be compatible with the level of reality it addresses. In this regard, ontological levels, such as micro, meso and macro, affect the set of methodological tasks of explanation and prediction (basic science), of prediction and prescription (applied science), and of the use of these methodological tools by the agents in the variety of contexts (application of science).

45 Ontological emergence “asserts that genuinely novel objects and properties emerge even within the domain of physics, and it rejects the idea that only the level of fundamental physics is real” (Humphreys 2016, xvii).
2.3.2.1 The Distinction Focused on Rules

Sometimes the distinction between micro, meso and macro is used from an ontological viewpoint, where the focus is on rules (Dopfer et al. 2004) especially in the case of economics. Thus, “the central insight is that an economic system is a population of rules, a structure of rules, and a process of rules” (Dopfer et al. 2004, 263). Kurt Dopfer, John Foster and Jason Potts reduce meso to “a rule and its population of actualizations,” meanwhile “micro refers to the individual carriers of rules and the system that they organize, and macro consists of the population structure of systems of meso” (Dopfer et al. 2004, 263).

However, this ontological architecture for a science, which is conceived as evolutionary (and, therefore, dynamic), seems to me to be partial, insofar as micro, meso and macro looks like a purely methodological approach that has ontological consequences. Moreover, in this view, the rules appear as more important than processes, which are certainly supposed by the rules. We can think of rules as part of organizations, which might be implicit or explicit, and are used in order to obtain some goals. Besides rules, there are genuine ontological components (individuals, groups, etc.), epistemological contents (organizations depend on knowledge to articulate the information available) and values (either implicit or explicit) that support the search of goals, the selection of means, and the evaluation of results.

A social ontology cannot be focused on a complete preeminence of rules, otherwise it is quite difficult to grasp many aspects, such as causality and causal explanation.\(^46\) Primarily, the three ontological levels mentioned can be considered regarding basic science. Thus, if the scientific explanation is causal, then features of causality such as specificity, stability and proportionality depend on only one level of reality studied.\(^47\) This is particularly clear in the features of specificity and proportionality in causality, because the relations between causes and effects require one to be on the same level of reality — micro, meso or macro — or, at least, to be on one level of reality that might be connected to the following one. The identification and individuation of causes in the micro level should be, in principle, easier to get than to do at the macro level, insofar as the degree of complexity is less intense.

2.3.2.2 The Case of Scientific Prediction

Scientific prediction does not depend only on rules and the temporal factor (such as the short, middle or long run) but also on the level of reality addressed by the predictive statements. Therefore, there are variations between prediction at the micro level, which might be particularly difficult (see Rescher 1998a, 1999), the meso level (such as multiple corporations and many medium size organizations), which has characteristics that might be more manageable than the prediction on

\(^{46}\)On causality and causal explanation, see Gonzalez (2018b).

\(^{47}\)These three features of causality appear in books such as Woodward (2003).
individuals or groups, and the macro level (such as nations or giant corporations and international organizations), where the size of the reality can make a better knowledge of the variables possible — in quantity and quality — than at the micro or meso levels.

Concerning applied science, the first step to guarantee is the scientific character of the predictions to be made. This means dealing with the impediments to predictability in any science. Commonly, they are studied in the case of basic science, but they might also concern applied science and they can spread from the application of science. These impediments are not mainly methodological but rather ontological and epistemological. De facto, the following main impediments are seen by Rescher in connection with basic science, and they are principally ontological and epistemological:

(1) Anarchy (i.e., lawlessness or absence of lawful regularities to serve as connecting mechanisms); (2) volatility (i.e., absence of nomic stability and of cognitively manageable laws); (3) uncertainty (i.e., the lack of information about the operative mechanisms); (4) haphazardness (i.e., the lawful linking mechanisms do not permit the secure inference of particular conclusions), which leads to three options: chance and chaos, arbitrary choice, or change and innovation (i.e., outcomes are not foreseeable because prediscernible patterns are continually broken); (5) fuzziness (i.e., data indetermination whether individually or in a collectively conjugate way); (6) myopia (i.e., data ignorance in the sense of lack of sufficient volume and detail to be able to make a prediction), and (7) inferential incapacity (i.e., the unfeasibility of carrying out the needed reasoning) (Rescher 1998a, 134–135).

Each impediment to predictability can be detected, in principle, at any level of reality (micro, meso, or macro). All of them have a relation with complexity — epistemological or ontological, either structural or dynamic, internal and external — because some of these impediments are mainly structural, whereas others are clearly dynamic. These impediments to predictability pose difficulties for a methodological universalism (Gonzalez 2012a) which is particularly relevant in biological sciences, where evolutionism has a dominant methodological role.48

Rescher recognizes that, for many writers, “complexity is determined by the extent to which chance, randomness, and lack of lawful regularity in general is absent” (Rescher 1998b, 8). But this concept of complexity, which is the inverse of simplicity, is an issue of degree: the system can be more or less complex. In the case of biological sciences, the tendency is to focus on some of the previous impediments to predictability, where uncertainty and haphazardness have, in principle, a relevant role from the methodological point of view.

48“‘In ordinary English, a random event is one without order, predictability or pattern. The word connotes disaggregation, falling apart, formless anarchy, and fear.’ This quote from the late Stephen J. Gould (1993) illustrates one reason why many nonbiologists — even highly educated ones — may feel uncomfortable with Darwinian evolution: Darwinian evolution centrally involves chance or randomness” (Wagner 2012, 95).
Obviously, complexity is the opposite to simplicity. But there are five possible concepts of simplicity: (i) parametric; (ii) theoretical; (iii) computational; (iv) epistemic; and (v) dimensional. These concepts are related to model selection (Rochefort-Maranda 2016, 261–279; especially, 269–274). Altogether these five versions of simplicity represent two main philosophical options of simplicity: epistemic and pragmatic (Rochefort-Maranda 2016, 261 and 274). The opposite notion — complexity — can be mainly epistemological and ontological with the structural and dynamic domains. But this complexity can be pragmatic in its models in two ways: (a) the scientific model is prepared with a purpose, i.e., it is oriented towards the resolution of a problem (theoretical, applied or of application); and (b) the model can be context-dependent and, therefore, connected to the agents.

Also, complexity in *applied science* is related not only to prediction but also to prescription, because any applied science requires giving the patterns for problem-solving (Gonzalez 2015b, ch. 12, 317–341). These patterns have a methodological component, but they also have epistemological and axiological components as can be noticed in the case of climate change (cf. Intermann 2015). Choosing the appropriate course of action for solving concrete problems (in physics, biology, economics, etc.) is not easy in many cases. Commonly, the complexity increases the difficulties of choosing the right course of action when we move from the micro level to the meso level or the macro level.

The next step is the *application of science*, which is clearly contextual and, therefore, pragmatic. When the issue of complexity is discussed in the sphere of the application of science, the levels of micro, meso and macro are particularly relevant. In addition, it is the issue of the kind of practical problem at stake (physical, economic, pharmacological, medical, etc.), which adds methodological diversity. This is particularly relevant in the case of medicine, where the relation between applied science (schools of medicine) and application of science (hospitals) is more intense and bi-directional. The micro level (a patient or a small group of patients), the meso (a larger group of persons with a common disease in diverse places) or macro (a pandemic with presence in several continents, as the case of Covid-19 emphasizes) are not the same.

2.3.3 **Structural and Dynamic Complexity from the Internal-External Duality**

Although the distinction between structural and dynamic complexity is key to this analysis of approaches to scientific method and the difficulties of methodological universalism, it does not cover the whole relevant field of complexity as it relates to the methodology of science. We also need the internal-external duality, which has epistemological content and ontological support. It is also connected to scientific values.
Complexity poses special difficulties for scientific methods due to the internal-external duality in scientific research, because the advancement of scientific knowledge for problem solving has to do with an environment with which it interacts. This makes it very difficult to have a methodological universalism “a priori,” that is, a method of general validity prior to or outside of a connection with the complex reality being studied. In this regard, besides the differences in approaches between structural and dynamic dimension of complexity, which can be found in diverse realms of reality (natural, social, and artificial), there is the internal-external duality.

This duality of scientific activity for solving problems (basic, applied or application) is particularly relevant in the case of the dynamics. Thus, there is an internal facet of complexity in the complex systems, which is especially noticeable in the social and artificial systems (e.g., in the Internet as platform for human information and communication) (cf. Gonzalez 2018c), and an external trait of dynamic complexity related to complex systems, which may be in different spheres: economic, legal, social, political, etc. (Gonzalez and Arrojo 2015).

There is usually an internal and an external perspective in philosophy of science: the former has dominated for decades the philosophy of science, whereas the latter has had its leading role in the authors of the “social turn” and in the studies of science, technology and society (Gonzalez 2006b). Both philosophico-methodological lines — the internal and the external perspective — currently coincide in ruling out the possibility that there may be “the” scientific method in the singular and all-encompassing, one of the main reasons being the internal-external duality in the dynamics of complexity.

Following this duality of internal and external, the dynamic complexity is reinforced if we think of changes in complex systems as being due to historicity, instead of considering them in terms of certain generic processes or some kind of evolution, because historicity emphasizes the variability of complex systems, which can lead to a quite different state of affairs than at the beginning, as happens when there is a revolution (such as in the cases of social revolutions or the digital revolution). Moreover, complex systems can be organized (such as a hierarchical or poly-hierarchical system) or disorganized (systems that might be chaotic, anarchic, etc.).

Historicity can be a central feature of the “internal” change of the complex system (particularly in social and artificial systems). In addition, it can also be a key trait of the “external” change of the complex system, because many complex systems are in a constant interaction with their environment (natural, social or artificial). This happens with the Internet, whose development — to a large extent — is due to the interaction with the users: individuals, groups, organizations, governments, . . . (Gonzalez 2020d). In addition, there are economic, legal, sociological, etc., aspects involved. Thus, a methodological approach needs to deal with internal and external dynamics of complex systems that are embedded with historicity.

Simon is interested in hierarchical systems, whereas Stiglitz considers the poly-hierarchical systems as well. See Simon ([1973] 1977) and Sah and Stiglitz (1986).
2.4 Empirical Sciences and Approaches to Scientific Method

Contemporary methodological approaches cannot overcome the fact that there are three main groups of empirical sciences: natural, social, and artificial. All are relevant to complexity. For a long period (at least since the mid nineteenth century), the methodological comparison between natural sciences and social sciences has been frequent. Meanwhile, there has been little attention to the methodological comparison between social sciences and sciences of the artificial, in general, and the sciences of design, in particular.50

2.4.1 Differences Between Natural Sciences and Social Sciences

Methodologically, the differences between natural sciences and social sciences are mainly in the Erklären-Verstehen controversy, which has at least nine options (Gonzalez 2015a, 167–188; especially, 173–177). The differences between “explanation,” conceived as the characteristic methodological approach to physics (and, thereafter, to the whole set of natural sciences), and “understanding,” seen as the specific methodological approach to history (and, consequently, to the whole group of social sciences), have been discussed since 1858. In the succession of positions over the years, the nine options pointed out (J. G. Droysen-W. Dilthey, M. Weber, logical positivists, Wittgensteinians, H. G. Gadamer, G. H. von Wright, K. O. Apel, A. Giddens-Ch. Taylor-R. Bhaskar, and H. Lenk) include relevant details on the methodological approaches, including those related to procedures and methods.

Nevertheless, there are some aspects that, in one way or another, call the attention of those who wish to emphasize that natural phenomena and social events require different methodological approaches. These discrepancies directly affect the methods of basic science and, thereafter, the methods of applied science but are also relevant to the application of science. De facto, although many philosophers and scientists accept a common methodological ground between both kinds of sciences, the Erklären-Verstehen controversy emphasizes the several methodological differences between them, which are connected to epistemological and ontological issues:

(a) Natural methods are commonly focused on “universal” phenomena in cases such as physical laws, which can usually be repeated, whereas social methods often need to deal with singular events in history, which in principle cannot be repeated in a strict sense (such as a battle or the death of a key leader). (b) Natural phenomena are usually beyond our scope in terms of intervention (‘we cannot decree a rainfall’ or ‘we cannot stop a hurricane’), whereas social events are led by intentionality and

50On the sciences of the artificial from the perspective of the sciences of design, the most influential book is Simon’s volume mentioned already, whose third edition was published in 1996. An analysis of the case of economics is in Gonzalez (2008a).
normativity, insofar as social events are related to human actions — individual and social — and they are oriented toward ends through decision-making and within a setting of implicit or explicit rules.

(c) The possibility of achieving objectivity by means of natural methods seems to be ordinarily guaranteed, especially in physics, whereas the acceptance of something as objective as a result of the research in social sciences is often controversial or even explicitly denied, mainly in cases such as historical events. (d) The status of the relations between researcher and the reality researched in the case of natural phenomena seems quite different from those in the case of social events, insofar as in social affairs the subject who does the research of the event is or might be at the same time — at least, to some extent — part of the object that is researched.

(e) Although natural phenomena require a context of interpretation of the data available and informative statements (e.g., in earthquakes we need a scale of interpretation of data), the role of interpretation is commonly stronger in the social sciences than in natural sciences. In this regard, some methodological views claim that the social events are usually built on a first kind of interpretation in order to characterize a social fact (and, therefore, it might be a plain construction), followed by a second kind of interpretation that inserts the social event into a wider framework (social, cultural, economic, cultural, etc.).

Given these methodological differences between natural sciences and social sciences, we do not exhaust the whole set of possible differences. Additional features can be found if we consider basic science, applied science, and application of science. In the area of basic science, the differences can be extended to the characterization of the explanations when they are causal or to the obstacles for prediction, which increase in social events in comparison with natural phenomena.

If we look at the sphere of applied science, there are also differences between natural sciences and social sciences in the relation between prediction and prescription, which are particularly clear in the case of prescription of patterns for solving problems due to social events, because scientific prescriptions (for example, in economics or demography) require special assessments based on the acceptance of values.

51The role of normativity, see Spohn (2011).
52On this issue, see Hacking (1999).
53The ongoing discussions on causality (such as actual causation, causal selection — one or several causes — and causal importance) might lead to differences between the cases of natural phenomena and social events. In addition, the features of causal importance might be of a different kind in natural phenomena than in social events. This concerns several aspects: (i) the causal responsibility (what produces the effect and makes the trait in the effect possible), (ii) the difference in the making of the effect, either actual or potential, and (iii) the causal specificity. Thus, natural intervention in physical phenomena and the agent intervention in economic events can have different characteristics.
54“Prediction is not the only exercise with which economics is concerned. Prescription has always been one of the major activities in economics, and it is natural that this should have been the case. Even the origin of the subject of political economy, of which economics is the modern version, was clearly related to the need for advice on what is to be done in economic matters. Any prescriptive
In addition, there are also methodological differences in the application of science, because in the case of social sciences the processes of application of knowledge need ethical values (e.g., in psychology or psychiatry). This shows the relevance of considering pragmatic complexity in addition to structural and dynamic complexity.

2.4.2 The Novelty of the Sciences of the Artificial in Comparison with the Social Sciences

Overall, there is a constitutive feature of novelty in the sciences of the artificial, insofar as they look for an extension or enlargement of human possibilities according to new aims, novel processes, and innovative results. Meanwhile the social sciences are commonly related to human needs, which seek universal features (social, cultural, political, etc.) in specific spheres. Thus, although the social sciences include many expressions of variation, they share some type of common roots that can be found in the past and the present, and they will appear again in the future in diverse forms.

Novelty in the sciences of the artificial, which are commonly applied sciences and have many applications, can appear in two main directions: horizontal and vertical. It is horizontal when the expansion is based on something previously available that is enlarged in order to reach new aims. It is vertical when the research moves up to get new aims that were not possible in the past, either as a new combination of existing elements (creativity as a reassemble of elements where new properties emerge) or as full-fledged creation of new elements (as happens many times with the creativity connected with the Internet).

Horizontal (or longitudinal) and vertical (or transversal) ways of novelty in the realm of the artificial can appear at the micro, meso or macro level. They can be seen in disciplines based on designs, such as communication sciences, economics or information science. All of them share designs that look for aims, being followed by processes in order to reach expected results. At the same time, they deal with complex systems. See Gonzalez (2011a, 2012b) and Gonzalez and Arrojo (2019).
to organize some libraries with books. Meanwhile, a vertical way of novelty at the micro level is in the programs for payments by cell phone instead of using checks or bank notes, the use of e-mails as a substitute for traditional letters, or the organization of the personal digital library of e-books and e-journals.

If the level is meso, we can find horizontal novelty in the programming for digital radio, in the design of marketing for a regional or state digital television, and in the scientific resources of the cell phone for direct intercontinental calls. Vertical novelty at the meso level appears in the programs for the Intranet of business firms or corporations, in the design of web pages as institutional images of a public or private university or center of research, or the organization of an electronic network of libraries using the same cataloguing system.

An additional degree of complexity comes from the horizontal novelty when the level is macro, such as the programming of digital television that has worldwide coverage (like television over the top, OTT), the design of financial products by the Federal Reserve or the European Central Bank that takes into account economic history (such as the 1929 crisis) to deal with the recent crisis, which began around 2007, and the designs for a European network of public libraries. Vertical novelty is in the new forms of communication based on the Internet, such as the design of social networks (either oriented towards friends — Facebook, Snapchat, etc. — or with a professional approach — LinkedIn, Mendeley, etc. —) or new informative means (Twitter, YouTube, etc., and those developed in China and India). Furthermore, all the expressions of financial economics related to international e-commerce include vertical novelty, and this kind of novelty is also in the designs of repertoires of bibliographical information with millions of references (such as Scopus).

Besides the twofold horizontal-vertical novelty, there is another duality that is methodologically relevant: internal novelty and external novelty. The novelty is “internal” or endogenous when the variations are made because of new processes needed for reaching new aims in order to get novel results (e.g., in the field of Artificial Intelligence or in the sciences of the Internet). The novelty is “external” or exogenous when the changes come from several sources: (a) the demands of the users (in economics through new accessibility for individuals, business firms, or international organizations for economic transactions; in communication through new programs for information, entertainment, etc.); (b) some legal dispositions (such as right to privacy or the “right to be forgotten,” etc.); (c) the new possibilities introduced by novel technological devices; etc.

All these forms of novelty due to the sciences of the artificial include aspects that are related to something that is de facto optional instead of being really needed. Thus, they add something that it is not merely social in the sense of based on human needs. This connects with what Ortega y Gasset used to call “supernature” (sobrenaturaleza), i.e., something that is added to what is really natural and,
therefore, is above what is originally natural. Thus, artificial is designed in order to grasp new possibilities for human beings, which we can see every day with the use of the Internet. This realm of the artificial is based on synthesis, whereas the social realm is developed with the role of analysis.

2.5 Coda

According to the analysis made here, the relations of the scientific methods with the levels of reality and complexity require a deeper view than the conceptions already available. (i) Methodological approaches are intertwined with the kinds of components: ontological (an object within a level of reality), epistemological (the advancement of knowledge in a basic, applied or of application setting), and axiological (the values that lead to preferences on the selection of ends and means of research). (ii) There is a methodological diversity, which starts with differences between the methods in formal sciences and empirical sciences, followed by differences in the methods used in natural, social, and artificial sciences. Thus, there is no basis for a methodological uniformity, either universal or sectorial, in science. In addition, methodological imperialism is problematic, even though there is an increasing need for interdisciplinary, multidisciplinary, crossdisciplinary and transdisciplinary studies in science. (iii) Methodological diversity and ontological levels (micro, meso, and macro) change the dominant view of an architectonic of science in terms of a building, where there are some fundamental parts understood as the basis for the bricks of knowledge of the other parts of the discipline. Thus, there is no genuine “fundamental” physics, chemistry, biology, etc., followed by the other disciplines in such an area of research. In addition, this new view fits in with the existence of phenomena such as the four forces of physics without a unified force to put them altogether in a consistent way. (iv) Complexity highlights the need for a pragmatic component of adaptation of methods to objects, where the objects are at a level of reality (micro, meso, or macro) and in a context of problems interrelated with other problems. This pragmatic realist view is in tune with a structural complexity and a dynamic complexity, where the models used — descriptive or prescriptive — can vary from one domain, such as natural sciences, to another domain, either social sciences or the sciences of the artificial.

59José Ortega y Gasset used this concept for the philosophy of technology, Ortega y Gasset ([1933] 1997, 23, 24 and 60). To some extent, it is a feature that is also valid for artificial designs, insofar as they enlarge the possibilities of what is natural in the human agents and societies in order to get new aims.

60Simon insisted on the feature of synthesis for the sciences of the artificial. See Simon (1996, 4–5).

61A development of this approach within the framework of scientific realism can be found in Gonzalez (2020b).
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