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Epilogue: Western Science, Reductionism and Eastern Perspectives

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Modern science originated in Western Europe, but its astonishing successes have forced every other civilization in the world to acknowledge and embrace its achievements. It is at the core of modernity and of the globalization of civilization. Consequently, efforts to show that non-Western traditions of thought should be taken seriously within the paradigm of science itself will inevitably provoke skepticism. However, science itself is riven not only by major problems and rival research programs, but by different conceptions about what is science and what are its goals. These have generated such confusion, even within such advanced fields of science as physics, that more and more scientists are examining non-Western traditions of thought to provide a sufficiently broad perspective to overcome this confusion, to identify the core problems within science and to redefine it and its goals. This special edition brings into focus such work in a historical-epistemological perspective.

The preface written by Robert Ulanowicz serves to highlight most of these issues. As a radical theoretical ecologist, Ulanowicz himself is centrally involved in challenging mainstream science, arguing that in future, ecology rather than physics should provide the model for scientific theorizing and explanation, and more broadly, how it should define its goals. He highlights the most important assumptions in science that have to be brought into question, and in some circumstances, replaced, most notably, those centering on the issue of reductionism. He argues that not only epistemological reductionism is being challenged by advances in science, but also ontological reductionism. This challenges the widespread view that science has always been reductionist and that to advance, it must continue to be reductionist.

But just what is reductionism? This notion has been deployed in diverse contexts and disciplines, and it is not at all clear that this is a univocal concept. Reductionism has been identified with Hobbes' resolutive-compositive method according to which to know anything it is necessary to analyse it into its elements, and then showing how compositions of these elements produce the behavior of the compound entity we are studying. The development of analytic geometry by Descartes' philosophy provided a different conception of reductionism based on analytic geometry, whereby position and extension were represented by coordinates, and by virtue of these, everything physical, including change and transformation, could be represented. Knowledge itself was also explained reductionistically, either following Descartes and the model of mathematics, analyzing knowledge claims into simple, self-evident truths and then building a system of knowledge out of these truths, or following Locke, by analyzing experience into elementary sense experiences and then showing how genuine knowledge could be built up from such elementary experiences, thereby distinguishing genuine knowledge from prejudice and superstition. In the early Twentieth Century, with further efforts to explain mathematics reductionistically by analyzing it into logic and set theory, in the case of Frege and Russell, or, in the Hilbert program, as axiomatized rules for the manipulation of symbols, these two characterizations of knowledge were combined with the development of logical empiricism, which reached maturity with logical positivism.

The goal of science was then defined as finding more and more general laws, expressible mathematically, through which measurable predictions could be made. While originally logical positivists were skeptical of postulated theoretical entities that could not be observed, in its mature form, the entities postulated by the most general theories were taken to be the ultimate reality through which everything else had to be explained and predicted. This was the hypothetico-deductive model of scientific theories. Science was seen to progress through 'theory reduction' whereby more specific theories were subsumed under and defined through more general theories, as for instance in the reduction of astronomy to mechanics, thermodynamics to statistical mechanics, or chemistry to quantum mechanics, and so on. This ensconced the elementary entities postulated by physics, the most general science, as the primary beings of the universe. This is the received view of science that permeates the thinking of most current scientists. In the early Twentieth Century it was used to defend and also influence the advances taking place in physics at the time, particularly quantum mechanics, which was marching towards further generalization and was being expanded to encompass all other disciplines.

With the defining goal of science taken by logical positivists and their successors to be the ability to make correct predictions, theory reduction as conceived by them was first and foremost epistemological reductionism (Nagel, 1961). Science progresses as more specific theories are deduced from more general theories, which extend the range of predictions. Epistemological reductionism was assumed to be supported by and to imply a) methodological reductionism, according to which the best way to investigate anything is to analyse it into its components and to examine the relationships between these, and b) ontological reductionism, according to which everything that exists or happens is a manifestation or effect of the primary beings or entities that constitute the universe, with the terms for all other entities being convenient means to identify what has to be explained, or explained away, as effects or manifestations of these basic entities.

It was acknowledged that in practice epistemological reductionism is impossible, however. Ludwig Bolzmann's project to explain the laws of thermodynamics through statistical mechanics was taken to exemplify a successful advance in science as defended by the later logical positivists (Suppe, 1977, 55f.). Bolzmann took as his starting point the laws of phenomenological thermodynamics. He analyzed gases into their components compatible with Newtonian physics, and then showed how extremely improbable states of these gases, for instance states with all atoms aligned with each other and moving in the same direction, would evolve towards the most probable arrangement, that is, towards maximum disorder, thereby accounting for the tendency for entropy to increase. It was recognized that concepts pertaining to aggregates such as entropy had to be used because of the impossibility of tracking every atom or molecule, but their use was seen to accord with the reductionist project of science that privileged the laws of motion and combination of the elementary entities. The development of statistical mechanics was part of Bolzmann's more general program, generally deemed successful, to show how aggregate properties of matter, such as viscosity, thermal conductivity and diffusion, are the effects of the properties of the mass, charge and structure of atoms.

Bolzmann's research program has dominated science ever since. The supposed explanation of living processes through biochemistry and molecular biology was among its greatest achievements. Mainstream complexity theory did not challenge this conception of science. The patterns examined by them were seen as effects of large numbers of interacting components and nothing more than this. Rejecting the focus and importance of more general laws by pointing to the enormous number of possibilities associated with the interactions between components of any aggregate to question the value of epistemological reductionism, is not a strong objection to the logical positivists' view of science. Logical positivists could accept such claims on pragmatic grounds while maintaining their commitment to epistemological reductionism via theory reduction in principle, if not in practice, as their fundamental goal, and along with this, methodological and ontological reductionism.

Epistemological reductionism is not only practically impossible, however, it misrepresents science and its greatest achievements. As Paul Feyerabend (among others) pointed out, the supposed examples of epistemological reductions given by logical positivists to illustrate their conception of science are invalid (1985, chap.4). For instance, Galileo's physics was not a special case able to be dealt with as such by the more general theory provided by Newton, and Newtonian physics was not dealing with a limited domain of reality revealed as such by the theories of relativity. Relativity theories fundamentally challenged the core concepts of Newtonian physics; that is, the very meaning of space, time, matter and mass, and Newtonian physics challenged the core concepts of Galilean physics. In each case, the supposedly more limited theories could not be deduced from these theories as special cases because the meaning of all the crucial terms had changed.

Pointing to the central role of concepts in theories showed that there is far more to science than making accurate predictions. If this were the case, Babylonian astronomy which could make more accurate predictions about the movement of stars and planets than Greek astronomy, would have to be regarded as superior to Greek science, although the Babylonians thought of the Sun, stars and planets as Gods, while Aristarchus argued that the Earth spins on its axis and revolves around the Sun, and that the stars are other suns at immense distances from the Earth. As astronomers came to realize, Aristarchus' astronomy was not only superior to Babylonian astronomy, it was superior to the Ptolemaic astronomy that succeeded it, where through the deployment of epicycles, it was always possible to make accurate predictions. Real advances in knowledge, illustrated by the development of Greek astronomy, are recognized as such because, as Kantians and post-Kantians realized, people ask questions based on their conceptual frameworks, and as post-Kantians realized, they can question and replace these conceptual frameworks to achieve deeper insight into the nature of reality. This reality must include the possibility of conscious beings who can ask such questions and set up experiments to find answers to them. The ability to make predictions is important, but is secondary to this quest for insight. It is for such reasons that Richard Feynman and Carlo Rovelli have opposed string theory, which is essentially a form of Ptolemaic physics, and Rovelli has invoked the astronomy of the Ancient Greeks as a model to guide physics into the future (Rovelli, 2011).

Revealing the logical positivists' fundamentally defective understanding of science and scientific progress does not invalidate methodological reductionism. Methodological reductionism involves carefully analyzing any subject matter into its elements, defining these precisely, and examining the relationships between them. It was developed and deployed as a method and utilized in diverse areas of inquiry by the Ancient Greeks, and it has been important to all subsequent thinking in the West and central to mathematics and science. It accounts for many of the greatest achievements of Western civilization. The axiomatization of geometry by Euclid illustrated the successful development and application of methodological reductionism, while the successes of biochemistry and molecular biology exemplify its achievements in modern science. If there is a scientific method, then methodical reductionism is central to it.

However, there are limits to what can be achieved by this method, limits evident in the failure of the Greeks to reduce geometry to arithmetic, and then in the Twentieth Century, to reduce mathematics to logic or the manipulation of symbols. Further limits to its application have been revealed in virtually every other area of inquiry and every discipline in modern science, despite successes. It is most evident in biology. Despite the achievements of methodological reductionism, sentient life becomes unintelligible when living organisms are analysed into their fractionated components, however these are conceived and identified. In fact, as a number of physicists have acknowledged, life is unintelligible through mainstream physics (Rosen, 2000, 7). Even in basic physics, methodological reductionism has become an obstacle to further progress. The bias towards analysis is evident in the continued pre-occupation with elementary particles, strings or branes, while the real progress has been based in quantum field theory developing the concept of fields and their transitions (Vitiello, 2001, chap.2; Hyland, 2015, 166, 190ff.). These cannot be entirely understood through analysis, although analysis plays a central role.

Emergence is central to biology, but not only biology. It is a phenomenon that cannot be explained in terms of its parts. For instance, the most basic field, the vacuum field, is a flux with no stable entities that could be identified, measured and used to explain the other fields that emerge from it (Moral and Marijuán, 2017). The fields that do emerge have components, which only emerge as part of these fields and cannot be isolated from them. For instance, crystals understood through quantum field theory cannot be understood as merely a structured arrangement of atoms or molecules. Crystals could not be manufactured by pulling atoms or molecules together. They are emergent, with phonons emerging with crystallization as force carriers or bosons to achieve long range correlations between atoms throughout the crystal, actively constraining them into structured wholes (Vitiello, 2001, 12ff.). They are vibrating, quantized fields. Phonons have to be accepted as real entities, but only exist as essential dynamic components of these crystals and cease to exist if the crystals are destroyed.

The problem of how to study such emergent fields is to work out what methods can be used beyond methodological reductionism to examine and comprehend such holistic phenomena. The supposed paradoxes and incomprehensibility of quantum theory, including the measurement problem, are really a manifestation of a dogged commitment to methodological reductionism, despite its manifest failures (Brooks, 2016). Various alternative methods are being developed, including the development and use of models that can only be related to observations and measurement very indirectly (Vitiello, 2001, 84), and radically new observational techniques that acknowledge that what we are studying is not independent of us – that we are part of the world we are striving to comprehend. Despite advances, there is no clear, final solution to this problem.

Showing that not even methodological reductionism can be upheld as the universal method of science does not invalidate ontological reductionism. Ontological reductionism is the commitment to explaining everything in terms of the primary beings of the universe, as aspects, manifestatins or effects of these primary beings. Commitment to such reductionism is sometimes held to be the basis of rational sanity. However, ontological reductionism is a problematic concept. The logical postivists' view of science, despite having been shown to be defective, entrenched the view that physicists are the pre-eminent scientists because of the generality of their theories, and that ontological reductionism involves accepting that it is the basic entities postulated by physicists that must be taken as the primary beings of nature, and everything else a mere manifestation of the behavior of these primary beings. There is no reason to accept this claim, and it has been resolutely rejected by Robert Rosen (2000, chap.2).

Rosen's argument is that if an ontology is to be adequate to account for every manifestation of nature, then it should first and foremost be adequate to life itself, that is, sentient life in which organisms are subjects as well as objects. This is a condition required for us to understand the possibility of science. Physics as it has been developed in the past deals with impoverished, non-generic aspects of nature in which life could not exist, and therefore must be seen as fundamentally defective. Similarly, he argued that if mathematics is to model life, then it has to advance beyond the impoverished view of it promoted Hilbert and Russell. This means that it has to abandon the belief that mathematical truths can be identified with what is computable, or that mathematical truths can be demonstrated through a simple reiterative procedure, or that to achieve rigor it is necessary to abandon impredicative concepts with circular definitions.

These problems are being recognized, and various paths have been proposed to overcome them. However, such proposals often have difficulty gaining traction. For instance, acknowledging the possibility of emergence and the primary reality of emergent beings is a challenge to past ideas of what counted as science. Emergence, involving real creativity, cannot be explained according to prevailing assumptions about what is an explanation. Those offering solutions to this problem are ignored by most other scientists because they break with embedded and, in the past, fruitful assumptions about what is scientific inquiry and what is a proper scientific explanation. The problem here is that it is extremely difficult to reveal the deepest assumptions dominating people's thinking, let alone to propose and take seriously alternatives to these, and if they are proposed and used successfully, to acknowledge the need to break with past assumptions.

The difficulty of challenging and replacing tacit assumptions was evident even among the natural philosophers responsible for the scientific revolution of the Seventeenth Century. Almost all major challenges to defective assumptions have drawn upon the history of thought to reveal when currently prevailing assumptions were first put forward, defended and accepted, before these assumptions had become so entrenched that they appeared unquestionable. Such historical work can reveal both the reasons for their acceptance, and their questionability. This was the case even with Descartes who was claiming a new beginning based on only accepting what claims to knowledge could be made with absolute certainty, but who defended this by offering a schematic history of past natural philosophy. Often, this turn to history has involved delving back into the distant past of European history, but as in the case of Leibniz and Schelling, it could also involve receptivity to the perspectives offered by the very different cultures of the East. The resulting revolutions in thought, almost always associated with reconceiving what is taken to exist, involve new forms of mathematics, new characterizations of what is to count as knowledge and as science, and new forms of reasoning. After all, we should recognize that the scientist as observer/participant/designer/modeler is part of the observation/participation/design/model process itself with both being simultaneously evident, thus demonstrating emergence as self-reference/introspection leading to comprehending/creating reality in a recursive/insightful manner towards obtaining the most optimal form and function. But this is the typical way of doing science, art/music, philosophy and even technology as an eco-balanced and socially internalized flowing process in the Eastern traditions, such as the Japanese *katachi* approach of achieving an ideal form with a deeper meaning of how it is bounded to function, which "(en)folds the act of observation into the model itself", (Cardier et al., 2017), in contrast to the often politically indoctrinated epistemological reductionism dominating science in the West. This is what we, in the West, can learn from the Eastern scholars to jointly develop an extended framework of science unifying and reconciling the Eastern and Western traditions of thought, (Cazalis, 2017). This special edition of *Progress in Biophysics and Molecular Biology* has grappled with this challenge in the quest to make life intelligible against the reductionism of mainstream science, and has engaged with non-Western thought in order to bring about the new intellectual revolution required to achieve this.

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