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THEMATIC ISSUE GUEST EDITORIAL

Quality & Quantity: Limits of Quantification in the Sciences

Isabella Sarto-Jackson[1] · Robert J. Richards[2] · Richard R. Nelson[3]

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This thematic issue compiles a selection of papers presented at the 30th Altenberg Workshop in Theoretical Biology held at the KLI in Klosterneuburg, Austria in June 2014. The workshop was organized by Werner Callebaut, Isabella Sarto-Jackson, and Richard R. Nelson, and distinguished itself by its very interdisciplinary character. As its title (given in the headline) indicates, this gathering of experts from various scientific fields was intended to advance the understanding of the relations between quality and quantity, and the limits of quantification in the sciences. Because of the explicit interdisciplinary nature of the effort, Werner Callebaut envisioned this topic to be attractive to a wide range of experts in the natural and social sciences as well as in the humanities. Sadly, Werner unexpectedly died a few months after the workshop. The authors of this thematic issue wish to dedicate it to the memory of Werner Callebaut, who inspired all the individual contributions.

This issue focuses on the fraught antagonisms between "quantitative" and "qualitative" research that abound in the scientific and philosophical literature–an opposition that fails to distinguish among various aspects of each of those concepts, and which neglects the possibility that in many fields qualitative and quantitative analysis are complementary rather than being oppositional. By way of example, in organic chemistry the description of molecules involves numbers but also figures and verbal description. The characterization is neither strictly "quantitative" nor strictly "qualitative" but rather involves elements of both. These paradigms seem to complement rather than oppose each other, and several of the articles presented here suggest that this is the case across a wide range of sciences. This thematic issue provides a framework that usefully accounts for the ontological, epistemological, and methodological aspects of "quality and quantity" talk, and enables a constructive debate on these and related issues.

In the arguments about quantity and quality three rather different issues are often conflated: characterization of the phenomena in terms of numbers; theory (articulation of causal relationships) using the language of mathematics; and research methodology. A clear distinction should be made between the use of numbers to characterize or describe the subject matter a scientific field deals with and the use of mathematics in its theorizing. While in many sciences the subject matter is largely described quantitatively, the underlying theory is not mathematical. In other sciences mathematical models are used to suggest what is going on in a subject whose description is largely qualitative. In addition, quantitative research methods, for example the use of statistical analysis employing quantitative indicators of the variables whose connections are being explored, further complicate the situation, because they rely on instruments that in general capture only partially the features of the objects under study.

The perceived qual/quant divide has roots in diverse intellectual heritages, including the Aristotelian tradition. One way of thinking that gained particular prominence

✉ Isabella Sarto-Jackson
isabella.sarto-jackson@kli.ac.at

Robert J. Richards
r-richards@uchicago.edu

Richard R. Nelson
rrn2@columbia.edu

1 The KLI Institute, Klosterneuburg, Austria

2 Morris Fishbein Center for History of Science and Medicine, University of Chicago, Chicago, IL, USA

3 Professor Emeritus of International and Public Affairs, Business, and Law, Columbia University, New York, NY, USA

after the Scientific Revolution is epitomized in Galileo's dictum that "the book of nature is written in the language of mathematics." In this view, mathematical theorizing can provide the basis of a unified theory of nature formalized in a universal calculus whose axioms and rules can be applied independently of the object under study. However, the laws of classical physics assume an exceptional position among the sciences. In fact, despite all efforts in the other sciences, physics appears to be the only science in which mathematical formalism plays such a constitutive role with respect to concepts and theories.

As the quantitative sociologist Otis Dudley Duncan wrote, "Nothing but physics is like physics, because any understanding of the world that is like the physicist's understanding becomes part of physics…" (Duncan 1984, p. 169). Apparent exceptions to this claim were the disciplines of population biology and quantitative genetics as being the first biological disciplines that were genuinely mathematized. Their central concept, viz. heredity, was originally treated as a measurable magnitude that played in biology a role similar to that of fundamental quantitative concepts in physics. However, Gayon (2000) convincingly showed that after a biometric, and a Mendelian genetics phase, biologists today no longer think of heredity as a measurable magnitude, but rather treat it as a structural property or the property of living beings in relation to their discerned levels of organization. But at the same time as revisiting the quantitative theory of heredity, ever more sophisticated quantitative methods and numerical description (i.e., equations) of phenomena were developed. Nonetheless, as Gayon points out, the current theory of heredity relies on basic causal factors and related functions and processes that are genuinely biological, not mathematical. Thus, he argues, heredity became the "central concept of a quantitative science without being itself a magnitude" (Gayon 2000, p. 86).

Other sciences and subfields within them, as well as interdisciplinary subfields in which physics intersects with other research areas, differ substantially from physics in the extent and ways in which they rely on numbers and mathematics. Natural sciences such as biology or geology are quite unlike physics: not only are many phenomena characterized at best only partially in terms of numbers, but also for the basic causal factors at work, the underlying theory is not expressed mathematically (see also the example above of population biology and genetics). Mathematical models are usually just used to help in thinking about causal relationships.

The use of mathematics in theorizing often goes together with the use of mathematics in the "phenomenology" of a scientific field (the description or characterization of the phenomena), but not necessarily so. Lord Kelvin referred to the issue of characterization when he said:

> [W]hen you can measure what you are speaking about, and express it in numbers, you know something about it: but when you cannot express it in numbers, your knowledge is of a meagre and unsatisfactory kind; it may be the beginning of knowledge, but you have scarcely, in your thoughts, advanced to the stage of *science*, whatever the matter may be. (Thomson [Lord Kelvin] 1891, p. 73)

This strong preference for numbers in characterizing phenomena in the sciences was spurred over centuries by the positivists, who endorsed the general goal of explaining the most phenomena with the fewest entities and assuming that an adequate account of science can only be achieved by having a formal mathematical representation of the nature of explanation and confirmation. This view also implied that most sciences are (still) immature and would come to resemble physics more as they "grow up." However, other scientists and scholars, following Francis Bacon's lead instead, have red-flagged the quantitative worldview, worrying that logic and mathematics might impose laws of their own to the detriment of the integrity of the object of research.

Nonetheless, logical-empiricist philosophy of science sanctioned the primacy of quantitative over qualitative research in all fields of the sciences (e.g., Benjamin 1937). This notion led to high expectations, suggesting that quantitative research methods are superior to their qualitative counterparts in terms of precision and rigor. Qualitative research, in contrast, was disdainfully disregarded as "nothing, but poor quantitative" (Rutherford quoted in West and Deering 1995, p. 14). The qual/quant controversy then peaked at the turn of the 19th to 20th century and developed into a bitter dispute in economics that also spread over to psychology and sociology. Researchers across scientific fields were continually looking for methods that would give definitive scientific answers—often turning to exclusively quantitative approaches, and thus often accused of "physics envy." At the same time, they risked constraining comprehension of their subject matter, which in many cases requires the kind of rich and deep understanding of phenomena that can only be gained through—iterative—quantitative and qualitative inquiries.

In outlining the contributions to this thematic issue, we will begin by invoking the following passage by the astronomer, physicist, and mathematician Eddington (1928, pp. 251–252; italics in original):

> Let us examine the kind of knowledge which is handled by exact science. If we search the examination papers in physics and natural philosophy for the more intelligible questions we may come across one beginning something like this: "An elephant slides down a grassy hillside …" The experienced candidate knows that he need not pay much attention to this; it is only put in to

> give an impression of realism. He reads on: "The mass of the elephant is two tons." Now we are getting down to business; the elephant fades out of the picture and a mass of two tons takes its place. What exactly is this two tons, the real subject matter of the problem? It refers to some property or condition which we vaguely describe as "ponderosity" occurring in a particular region of the external world. But we shall not get much further that way; the nature of the external world is inscrutable, and we shall only plunge into a quagmire of indescribables. Never mind what two tons *refers* to; what *is* it? How has it actually entered in so definite a way into our experience? Two tons *is* the reading of the pointer when the elephant was placed on a weighing-machine. Let us pass on. "The slope of the hill is 60°." Now the hillside fades out of the problem and an angle of 60° takes its place. What is 60°? There is no need to struggle with mystical conceptions of direction; 60° *is* the reading of a plumb-line against the divisions of a protractor. Similarly for the other data of the problem. The softly yielding turf on which the elephant slid is replaced by a coefficient of friction, which though perhaps not directly a pointer reading is of kindred nature […]. And so we see that the poetry fades out of the problem, and by the time the serious application of exact science begins we are left with only pointer readings […]. The whole subject-matter of exact science consists of pointer readings and similar indications.

Benjamin (1937, p. 16) cites this text to elucidate the role of philosophy in the qual/quant debate:

> The philosopher must tell us about elephants and hillsides and ponderosity, or more generally, about colors, sounds, odors, tastes, and touch sensations, and the complexes called "objects" into which they are united. But he must describe these in qualitative terms, not in measured values. […] The philosopher must pursue this qualitative element by *rational* techniques. The philosopher must restore to the world its expansiveness and durational character, which the scientist has replaced by meter sticks and clocks. […] Only through this supplementation can one understand the world in its totality.

The discussion around the "quantitative and qualitative" dyad is still alive in the contemporary sciences and philosophers of science have taken it on themselves to arbitrate between the two "camps." Many scientists aim to capture phenomena in numerical terms, because they consider such data as "hard" and reliable, suggesting objectivity. But it does not follow that quantification is able to avoid subjectivity on, say, individual, interpersonal, or political levels. In practice, scientists usually aim for consensus or intersubjective agreement as imperfect proxies for objectivity. This is recognized in calls for double-blind, randomized approaches, or similar "gold standards," indicating that subjectivity and objectivity are not opposites but, rather, mutually dependent.

In the natural and social sciences, qualitative research is often seen as an alternative and competing paradigm that—notwithstanding its presumed imprecision–uses rich data and acknowledges the observer's role in constructing the social world. Nonetheless, some of these disciplines have aimed to model themselves after the physical sciences, increasingly buying into the admonition of "measur[ing] what is measurable, and mak[ing] measurable what is not so."[1] Among these, it was economics that took the lead in using quantitative descriptions, employing mathematical models, and expressing theories largely mathematically. In this thematic issue, **Richard R. Nelson** discusses the great advantages for a field of science if the phenomena studied can be well characterized by numbers, and precise explanation for those phenomena can be expressed in mathematical form. But at the same time, if a field of science does not fall into these categories, forcing these quantitative and mathematical standards on them can seriously limit and distort the discourse, impairing the quality of the resulting explanations. He uses research by economists on economic growth to provide concrete cases of his general argument.

In other social sciences, the gap between the qualitative-historically and quantitative-theoretically oriented scientists widened with the development and spread of statistical methods and quantitative models. Critics worried that adopting predominantly quantitative research agendas might result in the narrowing and impoverishment of research goals and the relinquishing of more complete descriptions of phenomena, which are elusive under any circumstances. In her historical essay, **Katherine Nelson** illustrates these concerns by discussing two infamous psychometric examples, namely the quantitative measurements of intelligence and memory. She concludes that quantitative, laboratory-based experimental models—despite their ostensible scientific power—displayed blatant weaknesses in capturing cognitive abilities and have led research astray for several decades.

Overreaction to the deficiencies of "quantitative" research also has its pitfalls, however. **Olivier Morin** takes issue with the sweeping criticism that pinpoints shortfalls of mainstream methods in complying with the basic requirements of measurement. Acknowledging that in the social sciences, quantitative tools are often applied to parameters that can hardly be measured (such as preferences or

[1] This quotation is usually attributed to Galileo Gallilei.

happiness) or, conversely, for seeking binary outcomes from continuous measurements, he wryly terms these attempts "shmeasurement." He argues that these approaches are still of prevalent importance, because they have other functions than measurements, such as collating observations and deciding among competing hypotheses—thereby often relying on apparent "quantitative" modes without adhering to sound measurement procedures.

Debunking limits of quantitative assessments in climatology, **Evelyn Fox Keller**'s paper addresses the challenge that researchers face when dealing with risks of low probability–high impact events, sometimes in the distant future, as in the case of threats posed by climate change. In current models of expert risk analysis based on purely rational assumptions, for example, the absence of quantifiability calls for a novel conception of rationality: one that assumes bounded knowledge of experts and lay citizens alike based on context-appropriate heuristics. Such an approach could provide a more trustworthy basis for decision making and crafting responsible public policy.

Critics of quantitative research have distinguished two kinds of quantity–an extensive one, which lends itself to measurement, and an intensive one that admits only to "more or less." In this latter case, it is tempting to treat an intensive measure as if it were quantifying a pure quality. However, as Bergson argued, intensive differences may only amount to different sensations (Bergson 1913, pp. 71–72). Even it were theoretically feasible to denote each possible item in the world, the question remains of how many and which aspects might be excluded by this operation, and the caveat is put forward that a universal algorithm covering all the possible observables might not exist. **Liliana Albertazzi** offers an approach in her article to show how a science of qualities per se might be developed, one based on internal subjective parameters rather than on mapping to external stimuli. She rejects the judgment of "qualitative as poor quantitative" as methodologically unsustainable and gives examples of rigorous ways to conduct qualitative research.

Also drawing from the research field of sensory perception, **Ann-Sophie Barwich and Hasok Chang** discuss why sensory data do deserve the label of "measurement." In accordance with an epistemological view of measurement held in current philosophy of science, they argue that sensory measurements face the same epistemological challenges as physical measurements, namely the problems of coordination and standardization. Both issues must be addressed through a process of "epistemic iteration." The authors claim that a distinct separation of standardization and coordination might disclose sources of the apparently insufficient reliability of sensory measurement.

The long-standing supposition, described above, that qualitative and quantitative approaches are alternative and competing paradigms breaks down under closer scrutiny, since neither approach is uniquely identified by a particular epistemological viewpoint or a particular kind of data. A "methodological eclecticism" in which qualitative and quantitative approaches are deemed suitable for different purposes might also lead to the neglect of some important philosophical and theoretical issues, however (Hammersley 1996). Along these lines, **Fred Bookstein**'s paper clearly shows that in the natural sciences qualitative and quantitative analyses can be inherently complementary. He suggests that the modern biometrical statistics of organismal form is a particularly apposite disciplinary setting for exploring this dialectic claim. The cognitive/empirical cycling between the qualitative and the quantitative in reasoning about these questions are a matter of consilience across theoretical arguments, free from certain dogmas concerning "scientific method."

Isabella Sarto-Jackson advocates an extension of the classical ways of theorizing, describing, and analyzing of scientific data. In addition to quantitative–formalized (numerical) and qualitative–historical (narrative) approaches, she highlights the importance of visualization for a broadening of scientific conceptualization. Nonmathematical representations that afford multidimensional descriptions enable access from different methodological and cognitive angles. The advantage of having a large number of possible ways to represent objects or phenomena is particularly useful for the investigation of complex systems when scientific interests are heterogeneous (Griesemer 2000). Taking molecular biology as an example, she argues that its ascendancy was not least thanks to the exploitation of visualization.

Jorge Wagensberg, who unfortunately had to withdraw from participating in the workshop, has kindly contributed an essay in which he reflects on the quantity/quality duality as it relates to the growth of scientific and other cultural knowledge, and its presentation in public forums, such as museums.

In this thematic issue we attempt to go beyond the qual/quant dichotomy by neither following the analytic tradition of seeking to realign philosophy with the natural sciences, nor the Continental philosophers̓ skepticism about scientific reasoning itself. Current discourse affirms that this particular antagonism is outdated. We note the appeals to notions of qualitative versus undifferentiated quantitative growth in briefs for the Earth's survival. Quantitative growth of industrial production or gross national product needs to be valorized by "qualitative" or (more recently) "sustainable" growth. So, how can the falsely antithetic qual/quant positions be overcome? At the 30th Altenberg Workshop in Theoretical Biology on "Quality & Quantity," Werner Callebaut suggested taking advantage of the principles of the "post-dialectical dialectic" (Wallace 2005). Although some researchers might still argue that the discrimination of quality and quantity can enhance their research programs, antithetic thinking might more readily hinder conceptual advances than foster them. Since qualitative and quantitative aspects of research are intertwined on multiple levels, neither is more "fundamental." A clear-cut separation is bound to result in oversimplification of complex issues. As Levins and Lewontin (1985) asserted, a dialectical approach is a conscious challenge to major sources of error. Werner Callebaut concluded his presentation at the workshop with a citation from Trotsky (1939, p. 5):

> The dialectic is not a master key for all questions. It does not replace concrete scientific analysis. But it directs this analysis along the correct road, securing it against sterile wanderings in the desert of subjectivism and scholasticism.

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