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The sciences are different and the differences matter☆

Richard R. Nelson

Earth Institute, Columbia University, A-105, Hogan Hall, 2910 Broadway, MC 3277, New York, NY 10025, United States

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ABSTRACT

While biology often has been identified as the field of science where over the past half century progress has been most dramatic, physics continues to be the widely held model of what a field of science should aim to be like. The ideal hallmarks are quantitative characterization of the subject matter studied and mathematical specification of theory. The central argument of this paper is that the subject matter of many important fields of science is very different from that of physics – several of the physical sciences and much of biology, as well as the social sciences, are good examples – and that trying to ape the descriptive and analytic characteristics of physics in these fields hinders the development of understanding. Research on innovation is among this class.

1. Introduction

In a nutshell, the argument of this essay is this. For centuries Newtonian (and later post Newtonian) physics has been regarded by both scholars who analyze science, and laypersons impressed with the accomplishments of the scientific enterprise, as the model of what a science should be. It has been the hope, and the expectation, that if sufficient resources and talent were put into the sciences concerned with other phenomena – in particular the life sciences and the behavioral and social sciences – the kind of deep and broad and precise knowledge that had been attained in the physical sciences could be attained there too, and with that knowledge the ability to design technologies, ways of doing things more generally, that would be as effective in these arenas as the technologies made possible by physics. But this is an illusion. The subject matter of the other sciences is different, and the differences matter in terms both of the kind of knowledge and power one can expect from research in these fields, and the style of research that can be effective there.[1] It is important to recognize this, because otherwise there are strong tendencies to try to orient research in these other fields towards achieving the kind of understanding it cannot deliver, and to undervalue what it can.

Of course for many years this issue has been prominent in the arguments about what the behavioral and social sciences should be like, and whether physics provided an appropriate model for them to emulate.[2] But my argument here is not simply about the social sciences. It is that most of the biological sciences and a number of the physical sciences also are very unlike physics.

The recognition that the structure of different sciences needs to differ reflecting the particular nature of the subject matter they deal with is particularly important regarding the sciences that Stokes (1997) has proposed are in “Pasteur’s Quadrant”. These are the sciences concerned with important social problems and challenges, like holding off global warming, or stamping out or developing effective treatments for various diseases, or developing more effective ways of teaching children. Yet in science policy discussions the position often is taken that good research on issues like these should be modeled on research in physics. My position is that this mindset is a real problem.

This essay is organized as follows. In Section 2 I consider the particular characteristics of physics that have made it a model science, and argue that most other sciences are not like that because they cannot be. Section 3 lays out differences in the subject matters studied by different sciences, that cause the sciences to be different. In Section 4 I highlight the most important of these differences. Section 5 is concerned with sciences that study complex variegated subject matters, and particularly those expected to help us solve social problems. Finally Section 6 summarizes the main conclusions.

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E-mail address: rrn2@columbia.edu

[1] See Nelson et al. (2010) for an earlier statement of these issues.

[2] See various of the readings in Martin and Mcintyre (1994).

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2. Physics as a model science

I begin this discussion by noting that In recent years the assumption that physics provides a general model for all science to follow has eroded somewhat. The voices arguing that different fields of science are characterized by "Different Ways of Knowing", to use the title of John Pickstone's book, or "different styles of reasoning" (Ian Hacking's phrase), and that in many areas that scientists study there is a "Disorder of Things" (the title of John Dupre's book) that is quite unlike the subject matter of physics, have become stronger and more widely accepted among scholars who study science.[3] Scholars in this group clearly are proposing that the most fruitful methods of research and analysis and the kind of knowledge that can be gained in one field of science may not be like those in other fields.[4,5]

However, it is apparent that in many fields of science there continue to be clear signs of physics envy, and strong pressures to adopt more of the style of physics. And, as noted above, In science policy discussions there often is the presumption that all science should aim to be physics-like. There are three attributes of physics that seem particularly compelling: the quantitative specification of the phenomena being studied, the mathematical sharpness and deductive power of the theory used to explain these phenomena, and of course the precision and causal depth of the understandings of the subject matter it has addressed that physics has given us.

Over a century ago Lord Kelvin's stated baldly that "When you can measure what you are speaking about and express it in numbers, you know something about it: but when you cannot measure it, when you cannot express it in numbers, your knowledge is of a meagre and unsatisfactory kind". And this is the near consensus view today. Galileo's remarks probably are the most famous argument for mathematical theorizing: "The universe . . .cannot be understood unless one first learns to comprehend the language and interpret the characters in which it is written. It is written in the language of mathematics".[6] Today, there clearly is a widespread belief that mathematics ought to be the language for theorizing in virtually any science.

There is no questioning the amazing success of physics as a science of the subject matter it studies. The phenomena and regularities governing these it has brought to light have given us an understanding of features of the natural world that compares with what humans used to believe as day differs from night. And that understanding has provided the basis for the development of many of the technologies that enable us today to do things our ancestors could not even dream of.

And there is no question that the ability of physics to sharply characterize the phenomena it studies with numbers, and formulate its theories mathematically, has been an essential aspect of the great power physics has achieved. The quantitative characterization of the subject matter it addresses clearly is an important part of the reason for the precision of description and prediction it has achieved. While physics often employs verbal description, a hallmark of the field is that the important scientific aspects of the phenomena are stated as numbers. And the mathematical structure of its theories not only is an essential aspect of the amazing sharpness of the explanations and predictions it provides, but also enables productive deduction and calculation to an extent greater than that of any other science.[7] It is no wonder that scientists in other fields often suffer from physics envy, or that policy makers long for similar power in the sciences that bear on the problems they are trying to address.

But if the scholars of science referenced earlier are correct, this may be a fool's quest. The nature of the subject matter studied by a science strongly constrains the nature of the understandings that can be achieved and the methods of research and analysis that are likely to be productive in achieving them. My argument is that the subject matter studied by most sciences are not of the sort where the precise and compact quantitative characterization that marks physics is possible. In most of these fields numbers are an important part of the characterization, but only a part, and the numbers themselves reflect qualitative judgment. And in these fields the kind of precise law-like relationships that physics has identified simply may not exist, even in the sense of tightly stable stochastic relationships. For that reason, the core of theory is expressed qualitatively, although mathematical models may be employed usefully to explore certain logical relationships. On the other hand, the more qualitative understandings that these sciences can achieve can be illuminating and practically valuable. A number of the sciences whose understandings are strongly needed to help society deal more adequately with the challenges we presently are facing are of this sort, and tendencies to think of the knowledge they create as like knowledge in physics can diminish the ability of society to take advantage of the kind of knowledge they can provide.

3. I elaborate these themes in the following section. Different subject matters, different kinds of descriptions and understandings

The subject matter that is addressed by physics is quite special and seems particularly suited to quantitative and mathematical analysis.[8] Thus consider the Newtonian treatment of planetary motion, which continues to serve as a canonical example of successful science. The empirical phenomena addressed are the paths of the several planets, considered in the post-Copernican way as being around the sun. The location of any planet at any time can be described completely in terms of numbers, as can its motion at that time. Its closed path around the sun can be expressed in terms of parameters of the mathematical function that describe the shape of the orbit. Newton's explanation of the phenomena in question involves the mass of each planet and the sun, and how they relate to each other, as well as their locations, and this also can be expressed in equations and numbers.

Because of the limits many people have in their ability to visualize material expressed only in numbers and equations, texts and treatises in physics usually provide a graphic picture of planetary orbits, and a certain amount of verbal explanation. However, while a help to many people in facilitating their understanding, it would not appear that this part of the exposition contains substantive material beyond what is treated in numbers and equations.

The fruitful reduction of apparently complicated and varied phenomena to a set of numbers and equations is the hallmark of physics. That is what Newton did. Or consider modern astrophysics,

[3] Dupre (1993), Hacking (2002) and Pickstone (2000).

[4] In addition to the works referred to above, see for example Cartwright (1999), Giere (1990), Knorr Cetina (1999), Mitchell (2009), Whitley (2000), and Ziman (1991).

[5] I note that some years ago Ernst Mayr (1985) argued that biology differed from the physical sciences in a number of ways. The argument presented in this paper, while more general, has a lot in common with his.

[6] I want to highlight that quantitative characterization of the subject matter and mathematical formulation of theory are not the same thing.

[7] I note, however, that Thomas Kuhn (1961) has argued that much of the theorizing being done by physicists in the early stages of their efforts to understand phenomena is qualitative and that mathematical specification of theory often comes only after the questions being explored have been resolved in a way that is convincing to the physics community.

[8] Ziman (1991, p 80) has suggested that only phenomena that can be represented quantitatively and their relationships treated mathematically are permitted to be the subject matter of physics. Note that Kuhn's argument (footnote 9) would call for a slight modification of this position, but not a basic one.

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