# Myths About the Physical Sciences and Their Implications for Teaching Political Science

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This paper describes misconceptions about the physical sciences that are widely held by college students and that pose notable hurdles for appreciating the social sciences as legitimate scientific enterprises. My purpose here is pedagogical, too. In particular, I respond to the persuasive, specific argument in prior scholarship that students must overcome various negative or unconstructive stereotypes about the physical sciences to achieve scientific literacy.

Doubtless, scientific literacy is a complex concept, subject to various interpretations and hence methods of assessment (DeBoer 2000; Laugksch 2000). Yet a wealth of studies conducted over the second half of the twentieth century, employing a variety of methods—some assessing general understanding of science and its methods, some assessing "stocks" of scientific knowledge across a range of disciplines, and some exploring the understanding of specific scientific concepts or bodies of knowledge—have consistently found significant shortfalls in what could be deemed reasonable scientific literacy among American high school and college students (for an extensive review of this literature, see Lederman 1992).

A common conclusion of this research is that much misinformation about science takes the form of simplistic or flatly incorrect preconceptions or stereotypes. And one goal of education for scientific literacy is the eradication of such preconceptions. As Rutherford and Ahlgren (1990, 186) argue, "learners must change the connections among the things they already know, or even discard long-held beliefs about the world. . . . If their intuition and misconceptions are ignored or dismissed out of hand, their original beliefs are likely to win out in the long run, even though they may give the test answers their teachers want." In response to the preceding ideas I identify key misconceptions about the physical sciences that are widely shared by college students today, and I explain both why they are erroneous and how they are problematic for the teaching of social science. I also discuss how instructors can confront and overcome such misconceptions in the classroom.

The particular misconceptions about science that I attribute to college students are not unique by some criteria. *General public* misunderstanding of science is widespread and has been well documented. For example, the National Science Foundation's report, *Science and Engineering Indicators 2002* (National Science Foundation 2002), provides extensive discussion of this problem. Data from an NSF survey of the mass public cited there indicate that less than a third of Americans could be considered as "understanding the scientific process" and that large percentages of the public misunderstand a range of basic scientific phenomena. Worse, large percentages of the public believe in one or more forms of pseudoscience such as astrology, extrasensory perception, ghosts, faith healing, communication with the dead, and the existence of alien visitors to Earth.

Various deleterious consequences have been ascribed to the preceding mass beliefs. While many of those consequences should be of concern to all science educators, one of them is of particular interest for political scientists: whether a mass public that is not sufficiently knowledgeable about scientific affairs can play an effective role in the democratic process. As Prewitt (1983, 51) observes, "The lay public increasingly confronts a political agenda that has been fashioned by technical processes that only the experts can understand." An ill-informed public could, thus, communicate equally ill-informed messages about policy preferences through the mechanisms of the democratic process.

Social scientists may not have to confront in the classroom all the forms of skepticism and ignorance described by the National Science Foundation, although some of our students surely harbor one or more of them. Nor are all these forms of scientific illiteracy of concern to the present paper. I conclude that one of our greatest hurdles is of a more limited and particular character. Resistance to the belief that the social sciences are truly scientific arises especially from misconceptions about the physical sciences. We must recognize, challenge, and attempt to correct these misconceptions to successfully instruct our students in the scientific study of social phenomena.

I employ the term *myth* to designate these erroneous beliefs. Like most myths, those about the physical sciences are rooted in some accurate knowledge. But each one includes enough misinformation to qualify as a "long-held belief about the world," in Ahlgren and Rutherford's language, that is sufficiently misleading as to hinder a reasoned understanding of science.

And how did I uncover these myths? By one of the most respectable and fundamental of scientific procedures—direct and frequent observation of the subset of the mass public of interest here. I regularly teach an undergraduate course in the science and methods of political science. I also teach a graduate-level version of much the same course to first-year, first-semester doctoral students. These courses routinely address the scientific character of political science in detail.

I also query the students in these classes about the prior introductions to the social sciences, if they have had any, their perceptions of the legitimacy of the social sciences as sciences, and their objections to or reasons for skepticism about that designation. Prior exposure to this perspective in any notable degree is rare, even for the doctoral students. Yet, happily or not, the reasons students are skeptical about the legitimacy of the social sciences are few, consistent, and widely shared. The lessons I take from this kind of observation of our students provide the basis for the present paper.

## Myths About the Physical Sciences and How to Confront Them

My observation of and discussions with political science students and those majoring in various other disciplines reveal five especially common and critical myths.

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### *Myth 1: The Subject Matter of the Physical Sciences is Highly Orderly, Indeed, Deterministic in Its "Behavior"*

The invidious comparison, of course, in students' minds is that human behavior, some of the key subject matter for the social sciences, is highly unpatterned, disorderly, and unpredictable. And they believe that phenomena with the latter traits cannot be studied scientifically.

One might ponder how this myth arises. I suspect that the problem is largely caused by lazy or superficial thinking. Students likely assume that the orderly effects of gravitation in our immediate environment, as one example, or what they recall about the patterned character of many objects in our solar system can be generalized to all physical phenomena. Other observers, however, make a compelling argument that the *teaching* of physical sciences is one cause of this misperception. Delamont and Atkinson (2001, 87) observe of laboratory sciences that "undergraduate laboratory experiments have been chosen and stage-managed . . . so that they do, routinely, produce 'correct' results." Delamont and Aktinson make the same observation about instructional methods in field sciences. Further, the physicist A. B. Arons (1983, 100) argues that most science instruction and textbooks reify scientific knowledge, presenting it as "inevitable, rocklike formations that have existed for all time." Thus instructional practices and course content in many physical sciences characterize established knowledge in a way that re-enforces the stereotype of deterministic physical phenomena.

Whatever the source of this myth, we must confront and rebut it. I suggest two strategies for doing so. First, one might discuss with students some of the many physical phenomena that are known to behave in probabilistic, highly complex, or seemingly chaotic ways. Examples abound. But consider the following two: (1) The expectation of probabilistic instead of deterministic physical phenomena in quantum physics and its attendant expectation of *uncertainty,* where "the uncertainty is inherent in the nature of things and . . . the rigid connection between cause and effect is destroyed, because it is not certain that the cause will lead to the exact calculated effect" (Spielberg and Anderson 1995, 298); and (2) The unpredictable, trial-and-error character of the evolution of animal species, arising from randomly occurring trait variations and then "the natural selection of numerous, successive, slight, favorable variations" influenced to some degree, as well, by the external environment (Darwin 1998, 636–637). Second, one can encourage students to consider the complexity of some physical phenomena about which they may be especially interested. As one example, the average college student should not require much of a reminder that the effects of alcohol on the human body are complex and not entirely deterministic. To be sure, we could hope they know that enough alcohol consumed in a sufficiently short period will lead "deterministically" to intoxication, first, and death, second. But they also likely know that the effects of lower levels of consumption on mental and motor skills vary by one's weight, coincident eating pattern, drinking experience, and even individual tolerance more generally. Thus at some levels of consumption the effects across individuals are complex and variable. Equally, cigarette smoking—another subject of interest to many college students for various reasons—has a range of effects on the body. Even moderate smoking has certain deterministic effects on lung tissue. But the likelihood of contracting lung cancer even after a long period of smoking is either probabilistic in fact or simply understood as such by current medical science.

The central point to be made in response to this first myth is that natural phenomena—whether in the physical or social spheres—can evidence various different patterns of behavior. Such behavior might be deterministic or nearly so. It might instead only be probabilistically patterned, and with varying degrees of orderliness. It might even be chaotic. Thus the phenomena of interest to the physical and the social sciences are not remarkably different in these respects.

### *Myth 2: The Physical Sciences are Highly Successful in Explaining the Subject Matter They Study*

Students have a general perception of the physical sciences as being intellectually powerful and successful. But there is often little appreciation, unless one stimulates it, of the contingencies in the knowledge bases of those sciences or the existence of an intellectual frontier of unresolved puzzles. One approach for getting students to overcome this myth is to discuss examples from the physical sciences that contradict it. And abundant examples exist from the commentary of physical scientists themselves. An excellent one comes from the study of elementary particles in physics and the so-called Standard Model—the prevailing theoretical paradigm accounting for elementary particle behavior that has also been widely hailed as one of the most successful scientific achievements of all time. Yet Nobel-laureate physicist Steven Weinberg (2001, 199–200) has observed:

> "Even though the Standard Model provides the paradigm for the present normal-science period in fundamental physics, it has several ad hoc features, including at least eighteen numerical constants, such as the mass and charge of the electron, that have to be arbitrarily adjusted to make the theory fit experiments. Also, the Standard Model does not incorporate gravitation."

One could conclude on the basis of the preceding remarks that the Standard Model has a very long distance to go to account well for the real-world phenomena it is meant to explain.

Beyond using such particular examples, a second strategy is to encourage students to consider distinctions about the character of knowledge in scientific disciplines. A variety of treatments in the history, philosophy, and sociology of science agree that every scientific discipline has a body of knowledge that is generally accepted as useful description of or theory about its subject matter. Yet every discipline also has a good deal of other knowledge, often in the most recently completed or published research, that is controversial or the utility of which is not clear. For conceptual distinctions related to these different kinds of knowledge consider Kuhn's (1996) delineation of paradigmatic knowledge and that which challenges the dominant paradigm and Zuckerman and Merton's (1973) characterizations of codified, theoretical knowledge and more disparate, particularistic knowledge that is not codified into accepted general theory. Cole (1983) makes the especially useful distinction between the *core* of knowledge and that which is at the *frontier* of the discipline. Further, Cole (1983) has demonstrated with a variety of clever empirical analyses that the research practices at the frontiers of different sciences are essentially identical. And he demonstrates specifically that the work of social scientists at the frontiers of their disciplines is comparable to that of the same work by physical scientists.

It is widely agreed, then, that every discipline has a frontier of knowledge where existing research is of disputed



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or unclear utility. Older, more mature disciplines may have larger cores of knowledge than do younger ones, but all of them face a range of unresolved puzzles. Students who can appreciate these distinctions have a more sophisticated basis for comparisons of the physical and social sciences. And one could develop a host of specific examples where the physical sciences face notable problems at the frontiers of their disciplines. Davies (1995, 279–283) and Hagen (1997) present extended catalogues of unanswered, fundamental questions across a range of physical sciences—written for a lay audience. Alternatively, one can generate examples from those current scientific affairs that the mass media deem worthy of extensive coverage—and which, then, have considerable value for class discussion at the time they are newsworthy.

### *Myth 3: The Physical Sciences have Always been Highly Successful in Explaining Their Subject Matter*

This myth is a subtle corollary to the one above. If we lament that students know no history of politics, they are equally ignorant of the history of science—and with equally unfortunate consequences. Here, however, they have likely once heard examples from the history of science that contradict their misperception. But such examples must be evoked and re-interpreted to overcome the underlying myth.

One valuable approach here is to help students appreciate the differences between young and mature scientific disciplines. Young sciences commonly have limited ability to account for that portion of the natural world they study. If students can appreciate that all sciences were once youthful—as political science still is today—they will have a useful perspective by which to understand why and how the knowledge base of our discipline is limited.

Another educational strategy is to remind students of how recently many physical science disciplines accepted what we now know is quite erroneous or even destructive knowledge. Good examples are numerous. A useful contemporary one concerns diet and health. College students today are likely to recognize, for example, that modern medical and dietary science have exhibited notable controversy and reversals of conventional wisdom about the importance of different dietary components—protein, fats, carbohydrates, and nutritional supplements—for health. Even setting aside the numerous commercially entrepreneurial nutrition advice-givers, the strictly scientific community has at times advocated a range of different ideas, some of which have now been discarded or substantially qualified.

### *Myth 4: Concepts in the Physical Sciences Refer to Concrete, Easy-to-Understand Things Rather Than the Highly Abstract and Often Difficult-to-Define Phenomena that Political Scientists Study*

Students with little formal training in science rarely are able to think systematically about the *concept* of *scientific concepts*. And they are especially unlikely to recognize both the abstract and the operational components of such concepts. But very many of these students share a critical myth about concepts from the physical sciences. This myth suggests that the attributes of physical phenomena we endow with conceptual meaning are concrete aspects of physical things that exist regardless of whether and how we perceive them.

In contrast, students new to political science are uneasy about many of our central concepts. Democracy and autocracy as attributes of political systems and ideology, partisanship, and efficacy as attributes of individuals are too abstract and contestable, they believe, to form the basis for scientific study. Yet the view that political science concepts are usually abstract and that physical science concepts are especially concrete is based on a superficial misconception of the character of concepts in science generally. Likely every concept of importance in any science was once quite abstract and suffered contested meaning. Further, as Arons (1983, 92) explicitly argues, scientific literacy requires the recognition that all "scientific concepts (e.g., velocity, acceleration, force, energy, electrical charge, gravitational and inertial mass) are invented or created by acts of human intelligence and imagination and are not tangible objects accidentally discovered, like a fossil, a new plant, or a particular mineral." Arons goes on to explain, as well, how scientific concepts *routinely* evolve in meaning and precision.

Example concepts from the physical sciences for countering this myth are abundant, and they underscore both the intellectual disagreement that occurs in all disciplines *and* how intellectual progress often revolves around the resolution of disagreement about the meaning of core concepts. Arons (1983, 101) discusses the concept *force* from physics in this way, illustrating how its meaning has evolved—and in a fashion that can be readily generalized to political science concepts:

> "the concept of 'force' is legitimately introduced by connection with the primitive, intuitive, muscular sense of push or pull, but in the law of inertia, we redefine it to apply to any effect that imparts acceleration to a material object (for example, the action of an electrically charged rod on bits of paper). We endow completely inanimate objects with the capacity to exert forces on other objects (the charged rod exerting a force on the bits of paper, the table exerting an upward force on the book that rests upon it, the earth exerting a downward force on us—our weight—and an upward force at our feet). Following Newton, we then extend the concept even further and create the idea that when the table exerts a upward force on the book, the book simultaneously exerts a downward force on the table. We have come a long ways indeed from the original use of the word 'force' for an animate, muscular push or pull on another object."

The concept *force* shares close parallels with many concepts in political science. Consider the concept *democracy* as an attribute of a political system. Recall the limited, intuitive character of early, modern-science definitions of that concept like that of Lipset (1959, 71) where democracy "is defined as a political system which supplies regular constitutional opportunities for changing the governing officials. It is a social mechanism for the resolution of the problem of societal decision-making among conflicting interest groups which permits the largest possible part of the population to influence these decisions through their ability to choose among contenders for political office." Recall, too, how Lipset's operational definition of the concept democracy is based on what must be called casual observation of individual political systems.

Consider next, using Aron's terminology, how subsequent scholarship has "endowed" the concept of democracy with richer, more precise, and more complex meaning. This kind of conceptual elaboration and enrichment can be seen in various definitions based on the conceptual work of Dahl (1971), like that of Bollen (1980), or in the POLITY definition (Jaggers and Gurr 1995) that is based on the "patterns of



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authority" conceptualization from Eckstein and Gurr (1975). The operational definitions for the contemporary conceptions of democracy are also more complex (indeed, they are commonly multi-dimensional), explicit, and discriminating than Lipset's—another common product of conceptual elaboration.

The concept of democratization has been extended in other ways, too, just as has the concept of force. The range of application of the concept has been extended far beyond its original application to whole, national political systems. Democratization has been systematically applied to or assessed in such other institutional processes as subnational political systems (e.g., Hill 1994), election systems for particular public offices (e.g., Ragsdale 1989), and the comparison of alternative national election systems in polyarchic nations (Powell 2000).

One could develop other expositions of political science concepts that have evolved in the same way. But my principal concern is with the complexity of physical science concepts. Other notable examples from the physical sciences include: (1) Our students likely assume that commonplace physical phenomena like *light* have long been well understood by physical scientists. Yet the character of light was long contested—was light a wave or a particle? How was it transmitted and through what medium?—until well into the twentieth century (Park 1997, 310–338); (2) One might also assume that astronomers long ago settled the definitions of such common solar objects as *planets, stars, moons,* and the like. Yet the recent debate about whether Pluto is a planet reveals the limited precision of some of these concepts (Cowen 2001); (3) The concept of the *mass* of physical objects would also likely seem well established, and it has been a fundamental concept for theory in physics at least since Newton. But Weinberg (2001, 193–194) observes that Einstein's theory of general relativity created uncertainty for a time among physicists about how to understand mass. Indeed, one of Weinberg's (2001, 194) summary observations about this debate bears recitation: "Meanings [of concepts] can change, but generally they do so in the direction of an increased richness and precision of definition;" and (4) Consider the meaning of *time* as it has been portrayed in modern physics where "Einstein's theory of relativity introduced into physics a notion of time that is intrinsically flexible. . . . No longer could one talk of *the* time—only my time and your time, depending on how we are moving. To use the catch phrase: *time is relative*" (Davies 1995, 32–33). More complex still is the unified concept from relativity theory of *spacetime* (Davies 1995, 73).

### *Myth 5: Physical Scientists are Entirely Objective About Their Research and are Never Affected by Subjective Values or Preferences, Whereas Social Scientists Cannot Escape Subjective Biases Because Their Subject Matter is Humankind*

Students often make comments like, "No chemist would suffer affection for oxygen that would influence his or her work." Weinberg (2001, 200) echoes this sentiment when he observes, "We don't study elementary particles because they are intrinsically interesting, like people. They are not—if you have seen one electron, you've seen them all." But Weinberg, unlike the typical student critic, recognizes that passion in science is not so much about the phenomena themselves as about what explains their behavior. And scientists in all disciplines can be passionate about their theories and explanations, and their *individual* work can suffer—or benefit—from that passion.

Indeed, it is widely observed that all scientific disciplines are subject to the influence of creativity, passion, and discipline—and even bias, chance, and perfidy. Similarly, Cole (1983, 131) has argued that research at the frontier of every science is less rational than is widely believed. Zuckerman (1991, 151–181) explicates this circumstance especially well for students in introductory political science courses. Related to my central thesis, further, Arons (1983) faults the teaching of physical science once more for creating misconceptions about these facts. He argues that typical courses and textbooks isolate physical science knowledge from the human, fallible process by which it is created. Such treatments rarely encourage the student to appreciate the provisional character of that knowledge either.

The history of science is rich with examples of how knowledge is shaped by human values. Consider three examples where, respectively, knowledge has been influenced by sheer passion for one explanation of phenomena over others, by monetary gain, and by the gender of the scientist: (1) Referring to passion, Weinberg (2001, 201) describes the vehement disagreement among schools of physicists studying the origins of the solar system and observes: "I remember when most astronomers and astrophysicists were partisans of some preferred cosmology, and considered anyone else's cosmology mere dogma;" (2) On monetary gain, consider some of the scientific research on the effects of the weight-loss drug ephedra, that has been linked to over 100 deaths, including that of Baltimore Orioles baseball player Steven Bechler. Recent court findings indicate that some scientists doing clinical trials of the drug for its manufacturers misrepresented their results to make the drug appear more effective or less likely to have adverse side effects—because they were being paid by the manufacturers to carry out the clinical trials (Fessenden 2003); and (3) Even the gender of a physical scientist can shape research findings in the physical sciences. As Rutherford and Ahlgren (1990, 8) have noted: "for many years the study of primates—by male scientists—focused on the competitive social behavior of males. Not until female scientists entered the field was the importance of female primates' community-building behavior recognized."

Once they appreciate the general argument here about "irrational" influences on the beliefs and practice of individual scientists, students should be taught how the *collective* practice of science imposes safeguards, fallible though they can be, on the effects of such influences. The expectations of full disclosure of the procedures and evidence for one's findings, peer review for grant funds and publication, and healthy climates of skepticism and criticism help weed out faulty claims to knowledge. Indeed, one could argue that science benefits from a tension between the creative, passionate individual search for knowledge and the conservative, collective appraisal of the products of individual effort. And the latter process of collective appraisal seems quite healthy in political science—through vigorous debate and skepticism, and high standards of peer review.

## Conclusion

Seventy years ago John Dewey (1934) argued that the scientific community has as great an obligation to educate the mass public in an understanding of science as it does in advancing its own specialized professions and bodies of knowledge. Clearly, subsequent generations of scientists and educators have struggled to fulfill that



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obligation. Lamentations about the limited state of scientific literacy in the mass public have become commonplace over the years since Dewey's call, and there appears no reason to believe they will diminish in frequency—or that there is cause that they should. The evolution of political science in the twentieth century into a predominately scientific discipline means that we share the obligation Dewey articulated. But our goal, in my view, is not to join in the lamentations but to work at this task with the same passion we bring to our search for knowledge of political phenomena.

We have particular reasons, as well, to pursue this goal. As I have alluded to above, ours is a young scientific discipline that suffers the ignominies of all such disciplines. Among those is modest public understanding or appreciation. Indeed, skepticism about our scientific legitimacy is surely more common than is acceptance thereof. Thus we have compelling reasons to advance public understanding of our own discipline. And to achieve that understanding, we likely must convert one "mind" or one classroom at a time. We have the simultaneous goal, of course, of converting our students into political scientists—at least at some level of intellectual appreciation and, perhaps, of actual practice for the time they are our students.

Prewitt's (1983) concern about how scientific advances may compromise the role of the mass public in the democratic process suggests a second reason we should promote scientific literacy. Such literacy may be a fundamental part of civic education. Civic education often focuses on the machinery of government. But to the extent that it addresses the policy agenda of government, a basic knowledge of science, its uses, and its limitations seems essential for democratic citizens. Thus whatever we can do to advance scientific literacy may be central to the effective workings of democratic government.

There are doubtless many challenges for meeting the educational objectives outlined in the preceding paragraphs. A critical one, however, arises from the misconceptions students have about the more mature physical sciences—and the derogatory beliefs about the social sciences that result from those misconceptions. We must confront these myths directly in the classroom, employing as much creativity to dispel them as we bring to our substantive research.

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