The Resources, Powers, and Limits of Science

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The powers and limits of science have been identified consistently as an essential aspect of science education by the National Research Council of the National Academies, American Association for the Advancement of Science, and National Science Foundation. Their mainstream position is balanced and sensible, but it has not yet been supported with reasons. A reasoned account of science's powers and limits must explain and secure the resources needed to support conclusions about physical objects and events. The required three resources are appropriate presuppositions, empirical evidence, and standard logic. Mainstream science faces competitors that either diminish or else aggrandize science. Consequently, the scientific merit and future prospects of the mainstream position on the powers and limits of science could be improved by defending it with reasons based on science's resources.

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The powers and limits of science are an essential aspect of science education. The National Research Council (NRC) of the National Academies recommends that "Students should develop an understanding of what science is, what science is not, what science can and cannot do, and how science contributes to culture" (p 21 in 1). Likewise, the American Association for the Advancement of Science (AAAS) identifies this issue as a critical component of science literacy: "Being liberally educated requires an awareness not only of the power of scientific knowledge but also of its limitations," and learning these limitations "should be a goal of all science courses" (pp 20–21 in 2). The National Science Foundation (NSF) concurs that "every student should be presented an opportunity to understand what science is, and is not" (p 2 in 3). There has been a sustained call for scientists and nonscientists alike to understand what science can and cannot do. This topic of science's powers and limits entails an account of science's resources because they determine what science is or is not able to investigate.

This topic is important because of the social context of science. "The scientific enterprise is built on a foundation of trust" (p ix in 4). In order to merit this trust, an ethical responsibility for individual scientists and scientific organizations is to neither understate nor overstate the domain and abilities of science. The stakes are high because when trust is violated, the relationship between science and society is undermined (p ix). Furthermore, "Researchers seek to answer some of the most fundamental questions that humans can ask about nature," and "Their work can have a direct and immediate impact on the lives of people throughout the world" (p 1). Consequently, important intellectual, ethical, and pragmatic motivations energize the call for scientists and others to understand the powers and limits of science. However, there are two serious problems.

First and most obviously, the mainstream vision of science's powers and limits, which these position papers present, is hotly contested. Prominent cultural influences of relativism, skepticism, cynicism, and postmodernism diminish science, whereas the opposite influence of scientism aggrandizes science. One might wonder how this controversy impacts scientists, and how well scientists can articulate their own positions. For instance, for almost two decades I have taught a course on scientific method for undergraduate and graduate students, which includes the powers and limits of science. Few students can give a tolerable account of science's powers and limits, and virtually none can give principled reasons for their own views—and give good arguments against other views. Evidently, the commendable vision of a widely understood and accurate boundary around science's proper domain is not yet a reality.

Second, none of the position papers cited here defend their positions on science's powers and limits with reasons. This lack of reasoning is curious because the NRC calls for "scientific knowledge with understanding" or reasoning (p 21 in 1). It also warns against a "rather flat 'rhetoric of conclusions'" (p 111 in 5), that is, against giving conclusions without supporting reasons. A fundamental question is: What resources or premises are required to reach conclusions about physical objects and events? In other words, what information goes in so that scientific conclusions can come out? The answer might seem obvious and trivial: Evidence supports conclusions. Indeed, that answer has been promulgated in recent years by popular rhetoric about evidence-based science. However, scientific reasoning is actually more complex, as even a very simple example reveals. Envision a toss of an ordinary fair coin and ask, "Did the coin land heads or tails?" There are two hypotheses: "The coin landed heads" and "The coin landed tails." (Rare but possible outcomes like landing on the coin's edge can be excluded by specifying in advance that in such cases the coin be tossed again until it lands either heads or tails.) Suppose that we look and see tails. That evidence can be used in an argument with one premise that "We see tails" and the conclusion that "The coin landed tails." That informal argument might seem satisfactory, but actually it is incomplete. The logical problem is that the premise is about an observation, namely what we see, whereas the conclusion is about *something else*, an object, namely a coin, so the conclusion does not follow from the premise. As explained later, full disclosure of *all* premises requires the addition of two more premises in order to connect observation and object, and thereby to reach the conclusion. A satisfactory account of science's powers and limits depends critically on disclosing and securing *all* premises needed to reach conclusions, not just the evidence.

Frequent citation in this article of position papers on science from leading scientific organizations merits explanation because many scientists are unaware of them—although scientists are quite familiar with *Science* published by the AAAS and *Proceedings of the National Academy of Sciences (PNAS)* published by the National Academy of Sciences. Given the complex backdrop of conflicting and competing views on the powers and limits of science, position papers from the NRC, AAAS, and NSF describe and distinguish one particular position as being the mainstream position. The mainstream position on the powers and limits of science has great merit and balance, but it could be improved substantially by being presented and reinforced *with reasons* based on science's resources.

Probing Questions

Some advice from the NRC is particularly pertinent for the topic of science's resources, powers, and limits: "Ask probing questions that seek to identify the premises of an argument" (p 55 in 6). Naturally, the chief feature at the core of science's problem-solving abilities is "the attitude that data and evidence hold a primary position in deciding any issue" (p 27 in 5) and "Scientific knowledge is based on empirical evidence" (p 98 in 7). Although emphasis on evidence is appropriate for routine scientific work, examination of science's powers and limits involves a special kind of thinking, "Metacognition or 'thought about thought'," including "reflecting on the structure of one's knowledge and thinking" (p 111 in 5). If science is to be regarded as a rational activity with adequate resources to investigate the physical world, then several questions must be asked and answered. The first restates a fundamental question raised in the Introduction, and the next three are follow-up questions.

1. What are the requirements for full disclosure of *all* premises needed to support any scientific conclusion?
2. How can science's presuppositions be legitimated, even if they cannot be proved?
3. What renders evidence admissible and relevant?
4. What does science talk about, and how are those referents specified?

After these questions been answered satisfactorily, further questions can be asked about three competing assessments of science.

5. How can the mainstream position on science's powers and limits be supported with reasons?
6. What response can mainstream science give to diminished science?
7. What response can mainstream science give to aggrandized science?

The above questions are pertinent throughout all of the physical, biological, and social sciences. The following seven sections address these questions.

The PEL Model of Full Disclosure

What are the requirements for full disclosure of *all* premises needed to support any scientific conclusion? Historical perspective shows that this question has not been as easy to answer as one might suppose (pp 34–52 in 8). Around 300 BC, Aristotle raised this question. But there was an unresolved tension between his ideal science of geometry that featured deduction of theorems from axioms, and his actual science that required observations of animals and stars and other objects. A millennium and a half passed by until around 1300 when medieval luminaries—particularly Albertus Magnus, Robert Grosseteste, and William of Ockham—had first crafted a satisfactory answer. One of their revolutionary ideas was that knowledge of real physical entities (*scientia realis*) could not proceed by the same methods as knowledge of abstract logical entities (*scientia rationalis*), so science finally stopped trying to emulate geometry. Their intact and viable account of scientific thinking remains a magnificent intellectual achievement, especially because their aim was a decidedly human-sized account of science that explicitly considered the capabilities of human endowments. But unfortunately, during the past century, an understanding of all the resources required to support scientific conclusions has all but totally disappeared from the science curriculum.

As already explained in the Introduction, the informal argument from the single premise about the evidence that "We see tails" to the conclusion that "The coin landed tails" is actually incomplete. Symbolize we see tails by "S_t" and the coin landed tails by "C_t." Then the informal argument has the form "S_t; therefore C_t," which is a *non sequitur*. What is missing? Another requirement is the premise that "We see tails implies the coin landed tails," or symbolically "S_t implies C_t," which links human observation and physical object. This premise is the commonsense presupposition that seeing is believing, which includes that the physical world exists, our sense perceptions are generally reliable, and human language suffices for discussing such matters. With the addition of these presuppositions by the second premise, the argument becomes "S_t; S_t implies C_t; therefore C_t," which now follows the valid argument form *modus ponens*.

By definition, the presuppositions of a question or hypothesis set are propositions that must be true in order for all hypotheses to be either true or false. "A *presupposition* of a question is a thesis (or proposition) that is inherent in (and thus entailed by) each of its possible fully explicit answers" (p 5 in 9). For instance, in order for the hypotheses "The coin landed heads" and "The coin landed tails" to each have a truth value of either true or false, it must be the case that "The coin exists." Hence, the proposition "The coin exists" is a presupposition of the question "Did the coin land heads or tails?" The background experience and knowledge that we bring to our ordinary, everyday questions enables these questions to be focused and limited in scope. The question "Did the coin land heads or tails?" does question the coin's orientation and does not question the coin's existence. "The presuppositions of our questions reflect their *precommitments*: they constitute the formative background that we bring to the very posing of questions, rather than merely being something we take away as a result of answering them" (p 6). Indeed, "To pose or otherwise endorse a question is to undertake an at least tacit commitment to all of its presuppositions" (p 6).

Resuming the coin example, the argument has two premises so far, providing evidence and presuppositions. But it is still incomplete. To achieve full disclosure, the logic used here must also be disclosed by a third premise declaring that "*Modus ponens* is a valid argument form." Logic is needed to combine information in the premises "S_t" and "S_t implies C_t," and thereby to reach the conclusion "C_t." (Of course, the other possibility would be that we see heads S_h and the coin landed heads C_h.) Although rudimentary deductive logic suffices for this simple example, scientists utilize deductive logic (including *modus ponens*), inductive logic (including statistics), and many branches of mathematics (pp 112–173 in 8). The complete argument has three premises and achieves full disclosure.

Simple Example of Full Disclosure:

Premise 1, Evidence.	We see tails.
Premise 2, Presupposition.	We see tails implies the coin landed tails.
Premise 3, Logic.	*Modus ponens* is a valid argument form.
Conclusion.	The coin landed tails.

This example illustrates the general principle that every conclusion about the physical world requires premises of three kinds: presuppositions, evidence, and logic. This is the PEL model of full disclosure, named for its three components (pp 124–131 in 10; pp 78–84 in 8). The PEL model has an intellectual heritage from the *ex suppositione* reasoning of Aristotle, the conditional necessity of Albertus Magnus, the *scientia realis* of William of Ockham, the four rules of reasoning of Sir Isaac Newton, and the symmetry thesis of Thomas Reid (pp 41, 46, 74–76, and 176–177 in 8). The evidence concerns a human perception, whereas the hypotheses and conclusion concern something else, an external physical object; accordingly, presuppositions and logic provide the required link between perceptions and objects. The AAAS brings together the three resources of the PEL model as a basis for scientific conclusions in a suggestive remark about "the principles of logical reasoning that connect evidence and assumptions with conclusions," where "assumptions" may be taken as a synonym for presuppositions (p 27 in 11).

Legitimated Presuppositions

How can science's presuppositions be legitimated, even if they cannot be proved? The presuppositions of science cannot be proved or disproved by the ordinary means of marshaling evidence because any appeal to evidence has already implicated these presuppositions. Instead, presuppositions can be legitimated by basing them on our most confident and widespread knowledge about ourselves and our world. The NRC states that "Inquiry requires identification of assumptions" (p 23 in 1). Accordingly, position papers on science often identify science's presuppositions, such as "Science assumes that objects and events in natural systems occur in consistent patterns that are understandable through measurement and observation" (p 100 in 7). Likewise, "Science presumes that the things and events in the universe occur in consistent patterns that are comprehensible through careful, systematic study" (p 25 in 11; also see p 16 in 2). However, no reasons to accept these specific assumptions or presuppositions—and no reasons to reject contrary presuppositions—have been given in any position papers that have yet come to my attention.

The entire scientific enterprise needs to disclose and legitimate its presuppositions but once, whereas each scientific project requires its own particular collection of evidence. Legitimation does not involve learning new and erudite material; rather, it is an exercise in becoming self-aware of our own ongoing experiences and beliefs (pp 84–89 in 8). A key insight is that the presuppositions underlying the generation of facts "are not known to us or believed by us *before* we start establishing facts, but are recognized on the contrary *by reflecting on the way we establish facts*" (p 162 in 12). Accordingly, there are two steps to legitimate presuppositions: Identify some widely-believed and well-established facts, and then reflect on them in order to recognize what we have been presupposing all along about ourselves and our world.

The first step is selection of some commonsense knowledge about the world that is as unquestioned and widely known as is anything that could be mentioned. Common sense is the realm of our easiest knowledge—indeed, much of it is known by children only three or four years old. There are many good reasons for starting the journey of human knowledge with common sense (13). Significantly, the NRC gives science a grounding in, and continuity with, the interests and capabilities of children: "The research of the past few decades has thus revealed greater similarities between the concepts of children and those of scientists, avoiding simplistic dichotomies in which the concepts of the two are seen to be fundamentally different types" (p 106 in 5; also see pp 24–25 in 6). Any simple example of commonsense facts about the world would serve equally well, such as "Here is a glass of water" or "There are elephants in Africa." But for the sake of concreteness, the following *reality check* serves as an exemplar of unassailable knowledge that is comfortably within reach of ordinary human endowments and experiences: Stepping in front of rapidly moving cars is hazardous for pedestrians.

The second step to legitimate presuppositions is philosophical reflection on the reality check in order to disclose our presuppositions and to show that they also suffice for science. In order for the reality check to have been established by our experiences of life, the general makeup of the world cannot follow just any conceivable story. In agreement with the quotations from the NRC and AAAS in this section's first paragraph, the following statement offers a concise expression of these basic presuppositions: The physical world is real and orderly and we humans find it substantially comprehensible.

Further reflection on the reality check reveals three obvious and yet remarkable things about our world and ourselves. First, physical objects have properties and causal powers. For instance, impact from rapidly moving cars can cause harm or death for pedestrians *because* cars have the properties of being heavy and hard relative to humans. Indeed, "A major activity of science is investigating and explaining causal relationships and the mechanisms by which they are mediated" (p 79 in 7; also see 14). Second, reflection also reveals that humans desire to know and understand. Naturally, we need to know the reality check, and need to teach it to young children in the form "Look both ways before crossing a street," for its sheer survival value. But humans desire more than mere survival. Rather, "it is a remarkable fact about us that we cannot simply observe phenomena: we want to know *why* they occur" (p 3 in 15). For instance, we know the reality check not merely as a regularity, that being hit by a car is bad over and over again; but rather, we also understand and explain the reality check in terms of properties of objects and causes of events. Third, science has *public* status because of our shared human nature encountering our shared physical world, and that includes all humans having soft and vulnerable bodies relative to hard and rapidly moving cars. "In all cultures, whether they are highly technological or profoundly traditional, there are natural systems that everyone encounters in common and must explain;" for instance, everyone knows that "bounded solid objects, such as rubber balls, wooden doors, and rigid sticks … cannot move through each other" (p 56 in 5).

Science requires more experimentation, more data collection, more computation, more thought, and more work than common sense, but requires no further presuppositions. Indeed, any extraneous presuppositions would restrict science because whatever is presupposed cannot also be concluded. For instance, science can investigate the electric charge of electrons because science does not have any presuppositions about electrons. Science's ability to investigate so much emerges from its presupposing so little.

Admissible and Relevant Evidence

What renders evidence admissible and relevant? First, evidence is rendered *admissible* by presuppositions. Given commonsense presuppositions about the existence of physical objects and the sensory and mental endowments of humans, a report about seeing a coin is admissible. By contrast, different presuppositions, such as that the world is an illusion, would make observations of a coin or anything else inadmissible, thereby incapacitating science. Second, evidence should be *relevant* relative to the competing hypotheses, bearing differentially on their credibilities. For example, the hypotheses regarding the outcome of a coin toss disagree about what will be observed. Consequently, seeing that the coin landed tails is relevant because it confirms one hypothesis and disconfirms the other.

Presuppositions must be understood in order to elucidate the concept of evidence because admissibility inherently involves presuppositions. Presuppositions suitable for science are nondiscriminatory and indispensable. First, *nondiscriminatory* means having no positive or negative bearing on the credibility of any of the competing hypotheses. Appropriate presuppositions are nondiscriminatory precisely because they are shared in common among all of the hypotheses under consideration, in accord with the definition of a presupposition. For example, the hypotheses about the coin landing heads or else tails agree and presuppose that a physical object such as the coin is real and that humans can observe and discuss a coin toss. Second, as the PEL model explains, presuppositions are *indispensable* because there must be a link between perception and object in order to assert any of the hypotheses as the argument's conclusion. Likewise, logic is nondiscriminatory because it gives neither hypothesis about the coin any advantage or disadvantage, and yet it is indispensable for reaching any conclusion.

The three components of the PEL model—presuppositions, evidence, and logic—are complementary. Presuppositions and logic answer the question: How can we assert *any* of the hypotheses? Evidence answers the question: How can we assert a *specific* hypothesis rather than any of the others? Both questions must be answered. The role of evidence is to discriminate among the competing hypotheses in order to assert a specific one as the conclusion; but that role is inoperative without the support of logic and presuppositions that make it possible to assert any conclusion. Any discussion or defense of science's rationality that ignores presuppositions is provably incomplete and necessarily inadequate.

Specified Referents

What does science talk about, and how are those referents specified? That seemingly simple question is surprisingly complex and controversial. The character or nature of scientific knowledge can be approached in a concrete manner by considering typical knowledge claims in scientific journals. For instance, a recent issue of *PNAS* has information on decadal trends in the ocean carbon sink, the bacterial flagellar motor, germline chromosomes in songbirds, and targeted immune therapy to combat cancer. Obviously, physical objects and events are what that literature is about: oceans, bacteria, chromosomes, birds, humans, and cancer are typical referents of scientific literature. Equally obviously, science is done by humans, so scientific articles express human ideas and knowledge claims by means of words and images. Hence, science has a dual context of physical objects and human beliefs. Significantly, our most rudimentary knowledge has the same dual context: The reality check's referents are physical objects, namely moving cars and human pedestrians; and human endowments are presumed and displayed by our having acquired and communicated the knowledge expressed in its text. Accordingly, scientific literature resonates with the basic presuppositions recommended here that "The physical world is real and orderly and we humans find it substantially comprehensible."

Furthermore, given the dual context of physical objects and human beliefs, the correspondence theory of truth is applicable and meaningful: A statement is true if it corresponds with reality, but is false if it does not. For instance, the statement that "targeted immunotherapy may provide more durable remissions" than "tyrosine kinase inhibitors in treating cancer" is true if and only if that is the case for these physical objects and events, namely cancers, tyrosine phosphorylation inhibitors, and immunotherapy (16). The truth of this claim matters: It has practical consequences for mitigation of serious human diseases. Consequently, ordinary beliefs about a real, external, and mind-independent physical world that is accessible to human observation and comprehension—which is expressed in the recommended basic presuppositions—comports with typical science. This view is called scientific realism. It is sensible and prevalent, but not uncontested.

Imagine that the contemporaries George Berkeley, David Hume, Immanuel Kant, and Thomas Reid were together and they tossed a coin to decide between two pubs for having lunch (pp 36–37, 42–49, 74–78, and 93 in 8). All four would report the same experience of a coin, but their interpretations of that experience would differ. Berkeley would say that the coin does not exist as a mind-independent physical object, but only as a mind-dependent idea of a coin. Hume would say that science should concern our experiences or perceptions of the coin, whereas science cannot and need not know whether the coin exists. Kant would say that we know about the coin and phenomenal world as it appears to us, but not about the noumenal world as it actually is in itself. Reid would say that philosophy and science should follow common sense with a confident and cheerful certainty that the physical coin does exist. Likewise, imagine stepping two millennia further back and seeing Plato and his student Aristotle purchasing their lunch with a coin. For Plato, the coin would be but an illusory and fleeting shadow of its inaccessible but thoroughly real Form. But, for Aristotle, the coin itself would be completely real.

Unlike typical scientific debates about the evidence, this ancient and still ongoing debate is entirely about something else, namely the presuppositions concerning what is real and knowable. Despite their philosophical differences, Berkeley, Hume, Kant, Reid, Plato, and Aristotle could all agree that "The coin landed tails." There is agreement about the perceptions or appearances, although not about the referents and causes behind these sensory perceptions. The philosophical terms for what these otherwise diverse perspectives have in common is that they are "empirically equivalent," or they "save the appearances." Accordingly, willingness to assert that "The coin landed tails" is a true observation, with no deeper commitment to some metaphysics of coins, could be considered sufficient for science. Nevertheless, much can be said in favor of ordinary, commonsense, garden-variety realism. Anything else seems odd. For example, imagine reading an article by an idealist following Berkeley that began, "To be clear, by 'birds' I do not mean physical animals that eat physical food and breathe physical air, but rather I mean our ideas that we call 'birds' since only minds and ideas exist." Or imagine that an empiricist or skeptic following Hume wrote, "This article concerns human perceptions of oceans, but only perceptions and not physical objects."

The objection could be raised that much contemporary science is extremely weird and bizarre, so that tame examples of birds and oceans bias this discussion in favor of realism. Instead, if wilder examples were taken from quantum mechanics, cosmology, and relativity, then realism would seem misleading or simplistic. For instance, seemingly solid objects are actually mostly empty space. Perhaps our "common sense" works against, rather than for, our ability to see things as they really are, so the commonsense basic presuppositions are defective. Granted, science has given us many surprises relative to commonsense expectations. However, those surprises are conclusions of science, not presuppositions. Indeed, "Although through our theories, and the instrument-aided observations they lead to, we can go beyond and correct some of the pre-theoretical picture of the world we have by virtue of our being human, there is always going to be a sense in which all our knowledge and theory is based on elements in that picture" (p 95 in 17). Likewise, "We naturally and correctly expect observationally more remote theories to make some contact with the world of everyday experience, even if only at the level of registering meter-stick readings and traces on screens" (p 96). The supposed erosion of common sense by bizarre discoveries should not be overstated: Scientific knowledge of interactions between neighboring atoms in the solid state only confirms, rather than contradicts, that cars are solid objects when probed by macroscopic objects such as fingers, which is what common sense talks about. For these reasons, the surprising *conclusions* of science provide no basis for inferring that the *presuppositions* of science need to be different from those of common sense.

Scientific realism, which is rooted in science's basic presuppositions, provides the ideal context for science to operate with vigor and confidence. Significantly, if electrons and soybeans truly are real physical objects with properties such as a negative electric charge and protein-rich seeds, then these physical referents endow scientific realism with otherwise unapproachable explanatory depth and power.

Mainstream Science

The mainstream perspective on science can be expressed with beautiful simplicity, "science is the art of interrogating nature" (p 17 in 2). Given that project, position papers on science set forth an ambitious and sophisticated vision for what counts as success. Success criteria include accurate observation and description, predictive accuracy, parsimony or simplicity, testability, explanation of causes and events, unification of diverse phenomena, coherence with other well-established knowledge, and fruitfulness in generating new questions and further investigations. For instance, "The idea of cause and effect is fundamental to science—indeed, to making sense of existence" (p xiii). Science also contributes to technology, and thereby advances agriculture, engineering, and medicine. More generally, "Science is one of the liberal arts … unquestionably," and "The lifelong quest for knowledge of self and nature is the ultimate goal of liberal education," including the quest "to seek meaning in life" and to achieve a "unity of knowledge" (pp xi, 12, and 21). In that quest for meaningful life, the sciences are neither superior to, nor isolated from, the humanities; but rather, the sciences and the humanities are complementary and synergistic. Indeed, many of the "fundamental values and aspects [of science] are also the province of the humanities," so instruction in science "should include relevant relationships to the humanities" and science should be "integrated adequately into the totality of human experience" (pp xii, xv, and xi). The NRC states that "Scientific findings are limited to what can be answered with empirical evidence," so "Not all questions can be answered by science" and "there are other ways of knowing" (p 100 in 7).

It was noted earlier that science is public. But exactly what renders knowledge public? The PEL model can be used to frame this question in a comparative manner: What other knowledge is just as public as is elementary knowledge of the outcome of a coin toss, which was envisioned to illustrate the PEL model? Three conditions must be met in order for other knowledge to be just as public as this coin exemplar (pp 91–93 in 8). First, that other knowledge implicates the same presuppositions as the reality check and coin example. Second, the evidence is empirical and is available in principle to all interested persons by virtue of ordinary human endowments of reason and sense perception, like the widespread capability of humans to observe and know the outcome of a coin toss. Third, the argument's logic is as nondiscriminatory and unbiased toward its competing hypotheses as is the application of *modus ponens* in the coin example. As discussed in the preceding section on specified referents, not everyone accepts even rudimentary knowledge claims about coin tosses because radical skeptics reject them, empiricists restrict knowledge to sensory experience, and idealists deny that mind-independent physical objects exist. Nevertheless, an outcome such as “The coin landed tails,” construed in an ordinary and commonsensical manner, would count as knowledge for so many persons that it stands as an exemplar of public knowledge—not public in the absolute sense of satisfying every last one of this world’s several billion persons, but rather public in the practical sense of satisfying an extraordinarily wide audience of nearly everyone. When this notion of public knowledge is applied to scientific or other academic knowledge, the evidence and logic can be so technical that only experts can understand it. Hence, much scientific knowledge is not public in the broad sense that it is as easy for everyone to understand as is the outcome of a coin toss, but rather public in the relevant sense that unproblematic presuppositions, empirical and public evidence, and unbiased logic are credentials of knowledge claims that merit serious consideration by the scientific community. Of course, there are some exceptions to the general rule that science is publicly available because of national security, trade secrets, pending publication, and other considerations. The PEL model’s account of public knowledge illuminates the public status of science. Indeed, “Men and women of all ethnic and national backgrounds participate in science and its applications” (pp 28–29 in 11).

Importantly, the mainstream perspective acknowledges that scientific conclusions range in reliability from certain to quite speculative. “In reality, practicing scientists employ a broad spectrum of methods, and although science involves many areas of uncertainty as knowledge is developed, there are now many aspects of scientific knowledge that are so well established as to be unquestioned foundations of the culture and its technologies. It is only through engagement in the practices that students can recognize how such knowledge comes about and why some parts of scientific theory are more firmly established than others” (p 44 in 6). Accordingly, “The certainty and durability of scientific findings vary” (p 99 in 7). Some science is “unquestioned and uncontested, such as the existence of atoms” (p 79 in 6). This mainstream position is unproblematic and sensible because the same situation of varying confidence also occurs in common sense, history, and human knowledge in general. Nevertheless, compared to mainstream science, other positions either diminish or else aggrandize science.

Diminished Science

Some voices call for scientists to promise less and for the public to expect less—*much less*. They want diminished science, with few or no claims of rationality, realism, objectivity, and truth. Contrary to mainstream science’s diverse verdicts on the reliability of individual scientific claims, these critics propose a single universal verdict that all science is suspect, tentative, and revisable. Some philosophical attacks target all human knowledge, so they impact science even though they originate outside science (18). In response, if the doubt is extensive but does not reject the reality check, then one can ask the limited skeptic for a coherent account of why the reality check is not in trouble, but science is. On the other hand, if the doubt is pervasive and rejects even the reality check, then one can ask the radical skeptic whether obeying the reality check with one's feet in order to survive is compatible with doubting the reality check with one's mind.

Other attacks originate within science itself. Eliminative materialism is motivated and shaped by a particular interpretation of contemporary science. It claims that physical objects such as atoms and neurons are real, whereas human rationality, consciousness, and personhood are illusory and nonexistent (pp 202–210 in 17). But this variant of materialism places itself in the peculiar position of proclaiming arguments that are made by illusory persons who have illusory rationality, and are directed to other illusory persons who have illusory consciousness. More generally, any philosophical or scientific position that denies human rationality and consciousness needs to answer a charge of incoherence. To assert the reality check, or to know whether a coin landed heads or else tails, in a confident, nonnegotiable, and unassailable manner might seem like a small step. Nevertheless, for anyone possessing that confidence, radical skepticism and eliminative materialism are nonstarters—whether or not one locates the exact spots where long arguments for those views go awry.

Still other attacks come from some commentators on science who are rather well known to scientists. Much of what they say about science is insightful and helpful. But other elements, and even themes, of their thinking radically undermine science—or at least science according to the mainstream vision of the NRC, AAAS, and NSF. For instance, in an interview in *Scientific American*, Sir Karl Popper regards science as "a rational pursuit of the truth" and agrees that "a theory can be true;" and yet he adamantly denies that "we can ever *know* it is true" because scientific claims can only be proven false, but never proven true (19). In another interview, his student Paul Feyerabend insists on the "unknowability of reality" for "this one-day fly, a human being, this little bit of nothing," and he mocks pretentions of "searching for the truth" (20). And Thomas Kuhn says that "he is in fact pro-science;" and yet he describes science as being "arational," and he holds that "The real world is unknowable" (21). In such an intellectual climate, in which an arational science finds truth unattainable and the real world unknowable, science is far removed from its ordinary image. Understandably, some scientists who hold a mainstream position on science are alarmed by such views, as shown by a commentary in *Nature* and its subsequent correspondence (22; also see 23).

Scientist's perceptions of what philosophers say about knowledge and science affect the scientific community's perspective on science and its referents. Although some philosophers have exotic views that are potentially disturbing, such views are not as common as many scientists might fear. Actually, most philosophers' beliefs are congenial to science's basic presuppositions and scientific realism. Recently the first extensive survey of philosophy faculty was conducted, which obtained 931 responses (24). Regarding the existence of an external world, 81.6% of philosophers held non-skeptical realism, 4.8% skepticism, 4.3% idealism, and

9.2% other. Regarding science more specifically, 75.1% of philosophers held scientific realism, 11.6% scientific anti-realism, and 13.3% other. Consequently, scientists who are inclined toward scientific realism should realize that most philosophers agree with them, and they should not feel that the most sophisticated view of science is automatically deeply skeptical or hostile.

Many scientists are reticent to claim that any scientific findings are true or certain. Admittedly, some position papers express this view that "Scientific knowledge" without qualification "is tentative, approximate, and subject to revision" (p 20 in 2; also see pp 21 and 24 in 2 and p 26 in 11). Yet curiously, these same position papers also catalog literally hundreds of settled facts about the universe, the earth, cells, microbes, heredity, society, agriculture, manufacturing, communications, and other matters that are decidedly not tentative and not revisable. Hence, a charitable reading of these documents perceives the overall message to be that scientific findings are variously established, ranging from quite tentative to certainly true, in line with the mainstream position in the previous section. Fortunately, some other position papers present a clear and balanced perspective. The NRC challenges exaggerated accounts of scientific revolutions: "Einstein's general theory of relativity was a true scientific revolution" that "redefined conceptions of the nature of space and time," and yet "it did not invalidate all that had gone before; instead it showed clearly both the limitations of the previous theory *and* the domain in which the previous theory is valid as an excellent (close) approximation" (p 33 in 5). The lesson drawn from this example is that well-tested and established theories "are tentative in domains in which they have not yet been tested, or in which only limited data are available," whereas they "are far from tentative in the domains in which they have repeatedly been tested" (p 33). Currently, there are unresolved issues related to the theory of general relativity because a consistent union with quantum field theory that is free of renormalization troubles is still elusive. But just like the previous transition from Newton to Einstein, future refinement would not invalidate contemporary physics wholesale. The NRC explicitly rejects the "mistaken impression" that "uncertainty is a universal attribute of science" (p 44 in 6).

Aggrandized Science

Some scientists and scholars propose that science is the sole provider of real knowledge that counts in public discourse, which is a posture called scientism. A chapter "In Defense of Scientism" by authors who "admire science to the point of frank scientism" provides a helpful introduction to this position (p 61 in 25). The basic contention is that "With respect to anything that is a putative fact about the world, scientific institutional processes are absolutely and exclusively authoritative," and "science respects no domain restrictions and will admit no epistemological rivals (such as natural theology or purely speculative metaphysics)" (p 28). Indeed, when we encounter questions that science cannot answer, "This does not imply that we should look to an institution other than science to answer such questions; we should in these cases forget about the questions" (p 30). Their overall objective is "to defend a radically naturalistic metaphysics" such that "our philosophy of science and our scientistic metaphysics reciprocally support each other" (pp 1 and 65); that is, they intend to connect science and naturalism inseparably. Likewise, "no alternative kind of metaphysics can be regarded as a legitimate part of our collective attempt to model the structure of objective reality," so scientism insists that naturalism uniquely befits our collective or public knowledge of reality (p 1).

By contrast, position papers from major scientific organizations, as already quoted, respect relevant relationships with the humanities, encourage integration of the sciences into the totality of human experience, and acknowledge ways of knowing besides science. These commitments entail a rejection of scientism, even though these position papers do not engage and refute scientism directly. But cogent scientific and philosophical arguments against scientism and its variants can be found elsewhere (26–28). As scientists consider the literature for and against scientism, awareness of the PEL model may clarify some underlying issues.

Scientism claims, as noted above, that scientific institutional processes are the exclusive providers of legitimate knowledge. By contrast, the PEL model is developed in the commonsense context of coins being tossed and pedestrians avoiding car accidents, so there is nothing distinctively scientific about it. Indeed, philosophy in particular and the humanities in general also generate some knowledge claims by appeal to empirical and public evidence in accord with the PEL model—although they employ additional methods, such as conceptual analysis. Consequently, the broad applicability of the PEL model supports the previously quoted AAAS position that many of the "fundamental values and aspects [of science] are also the province of the humanities," as well as the NRC position that "there are other ways of knowing" besides science. The extent of applications of the PEL model in the humanities depends (as always) on the availability of empirical, public, and adequate evidence for particular knowledge claims, which must be judged on a case-by-case basis. The full benefit from empirical and public evidence arises from welcoming such evidence whether it occurs in the sciences or the humanities.

Scientism also claims that philosophy of science and a radically naturalistic worldview support each other. What is clear from the PEL model is that arguments for an alliance between science and any worldview have two options: Worldview content may either enter the argument as a presupposition, or else exit the argument as a conclusion based on empirical and public evidence. The first option has augmented presuppositions of the form, "The physical world is real and orderly and we humans find it substantially comprehensible, *and* worldview *X* is true." Of course, whether an argument hinges on presuppositions or else evidence has consequences for the breadth of the audience that might be expected to find it interesting. However, what is disallowed are circular arguments for a science-worldview alliance that have the same worldview content appear as both presupposition and conclusion because that constitutes empty reasoning. Rather, what is easiest for an audience to consider and evaluate are precise arguments in which the logical role of the worldview content—as either presuppositions or conclusions—is stated explicitly, clearly, and accurately. Also, arguments that use evidence to draw conclusions will be most effective if they use logic that treats competing hypotheses or worldviews in an equal, unbiased, and symmetrical manner.

The traditional view of science—as one way of knowing—has much to commend it. "The method of natural science is not the sole and universal rational way of reaching truth; it is one version of rational method, applied to a particular set of truths" (p 134 in 29). Likewise, "rationality should not simply be identified with it [science]," but rather "science itself stands in need of a rational underpinning" (p 5 in 30).

Discussion

Because position papers from the NRC, AAAS, and NSF have presented the mainstream perspective on science's powers and limits without reasons based on science's resources, their potential impact on the ongoing competition among diminished, mainstream, and aggrandized positions has been impaired. What is the way forward? My suggestion is to begin with an incisive question that is equally relevant and fair from all perspectives, namely this article's first question: What are the requirements for full disclosure of *all* premises needed to support any scientific conclusion? That is, do scientists have adequate resources to support conclusions about the physical world?

The PEL model recognizes three resources: presuppositions, evidence, and logic. Contemporary scientists already have effective procedures and instruments to acquire data and evidence, and likewise powerful logic and mathematics (and computers) to analyze data and assess evidence—and year by year, they improve. But this is only two-thirds of science's required resources. The underdeveloped third has been science's presuppositions, which are indispensable. Indeed, without an explicit account of presuppositions, it is absolutely and provably impossible to explain how science has any admissible evidence, to specify what science refers to or talks about, to defend science's rationality, and to understand how science reaches any conclusions whatsoever. Consequently, a strategic move for mainstream science would be to restore presuppositions to their proper and essential place in the science curriculum. Only the complete resources of presuppositions, evidence, and logic can provide a reasoned account of science's powers and limits that is balanced, responsible, and defensible.

Conclusions

Several key ideas capture the essence of this article. Mainstream science's position on the powers and limits of science, unlike its competitors' positions, can be given an intellectually rigorous defense based on the resources of science, namely presuppositions, evidence, and logic, as specified by the PEL model. Presuppositions and logic answer the question, "How can we assert *any* of the hypotheses?," whereas evidence answers the question, "How can we assert a *specific* hypothesis rather than any of the others?" A helpful way to assure the full and proper influence of evidence is to handle the accompanying presuppositions and logic skillfully. The current intellectual climate of vigorous debate about the powers and limits of science behooves proponents of mainstream science to present their position *with reasons* based on a viable account of the resources of science.

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