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ARTICLE

Scientific Knowledge vs. Knowledge of Science

Public Understanding and Science in Society

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Abstract
How is knowledge pertaining to science best transferred to the public in order to bolster support for science-based policy and governance, thereby serving the common good? Herein lies a well-recognized challenge: widespread public support arguably requires a widespread understanding of science itself, but this is naturally undermined by the inherent complexities of the sciences, and by disparities in teaching and popular reporting. A common reaction to this has been to champion educational reform to produce broader scientific literacy, but prevailing conceptions of this, I argue, are misconceived. I consider an account of "knowledge transfer"—a practice whereby science is "transferred" between different contexts of use—to illuminate why some transfers are successful and others are not, and thus, why conventional appeals to scientific literacy are bound to be ineffective in producing public understanding that serves societal wellbeing. As an alternative, principal focus, what is required is a form of philosophical literacy regarding science, amounting to a particular understanding of the claim that "Whatever natural science may be for the specialist, for educational purposes it is knowledge of the conditions of human action" (Dewey, 1916, p. 128).

Keywords Public understanding of science · Common good · Scientific literacy · Nature of science · Success of science · Scientific instrumentalism

1 Bringing Science to Bear in Pursuit of the Common Good

Many would agree that in addition to the important intellectual functions science may serve, satisfying desires for knowledge and explanation regarding the natural and social worlds in which we live, one crucial function is to contribute toward improving the welfare of those who inhabit these worlds, thereby serving the good of individuals, groups, and societies. Appreciating that interests can diverge and must be negotiated, let me refer to this simply as "the common good." In a democratic society, in order to bring our best science to bear successfully (or at least as effectively as we can) in making such contributions,

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widespread support of this particular role for science seems essential, since widespread support is generally (though not always, of course) a major determinant of public policy and governance by elected representatives. Indeed, public support is clearly a non-negligible factor in shaping policy and governance in some non-democratic societies as well. Many would further agree that the most obvious route to widespread support of this kind is widespread understanding: the greater the extent to which society as a whole understands our best science, the greater the likelihood of consequential public support for science-based policy and governance. Finally, it is a truism that public understandings of science are a function of science education, whatever forms this may take. I will assume all of this agreement as a starting point in what follows.[1]

Assuming all of these things, however, leaves much to be clarified and disputed about what *sort or sorts* of scientific education would, in fact, serve the goal of enhancing public support for the uptake of science in confronting the many challenges societies face. For one thing, there are many different challenges to scientific understanding, and having a clear picture of them may suggest the appropriateness of different antidotes in different cases. For another, wherever scientific education may be an appropriate antidote, it remains to be agreed what this education should comprise, exactly. My aim in this essay is to argue that common conceptions of the public understanding of science, corresponding to common conceptions of scientific literacy—while laudable in their own right—are not well suited to the task of enhancing public support. I will argue for a different conception: one that emphasizes a particular understanding of what science is and can deliver, as an instrumentally successful, problem-solving endeavor, that is shared by all and otherwise conflicting accounts of the nature of science. I will conclude with some incipient thoughts on what insight this may offer concerning the question of which remedies would best address various sources of science skepticism.

In Section 2, I will briefly review the main challenges to improving levels of public understanding, and how this is naturally connected to prospects for widespread public support for science-based policy and governance. The most frequently advocated proposal for elevating public understanding, namely, changing educational priorities in such a way as to improve levels of scientific literacy, is considered in Section 3. Here I will argue that, as they are generally conceived, the two most prominent versions of this proposal in recent decades—focusing on improvements in teaching the content of scientific theories and models, including the skills and concepts required to engage with them ("scientific knowledge"), and focusing instead on the practical realities of how science works (knowledge of scientific practice or, as it is often labeled, "the nature of science")—are likely to be ineffective. Taking inspiration from recent discussions of the idea of knowledge transfer in the philosophy of science, concerning ways in which knowledge is often extracted from one scientific domain and made to function in another, I will then explore conditions under which transfers are successful, in Section 4. This discussion clarifies the negative

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[1] For summaries of work concerning the aims of scientific education, see Smith & Siegel (2004, 2016). For studies of the many consequential relationships between scientific literacy, responsible citizenship, and democracy, see Dewey (1916), Miller (1998), Longbottom and Butler (1999), Kolstø (2001), Holbrook and Rannikmae (2009), Kitcher (2011), Ratcliffe and Grace (2003), Reiss and White (2014), and Sadler and Zeidler (2009). For literature surveys of frameworks for analyzing public understanding (including scientific literacy) and enhancing this understanding (e.g., by means of science education) to facilitate science-based policy, see Bauer et al. (2007) and Kappel and Holmen (2019), respectively. For some recent empirical data on correlations between science education and public understanding, see Kennedy and Hoffman (2019) and Besley and Hill (2020).

conclusion of the previous section, and sets the stage for a positive proposal, the beginnings of which are sketched in Section 5: emphasizing an understanding of the sciences according to which, in a perpetually evolving and corrigible way, they incorporate our most effective strategies for grappling with concrete problems.

As a final word of introduction, it is worth flagging that at every stage, I will attempt to convey the entirely constructive aspirations of this discussion, which ultimately amounts to an argument for educating people in such a way as to entrench a kind of *philosophical* literacy with respect to science. This prescription is hardly incompatible with the inherent value of learning how to understand scientific theories and models, or the value of learning about how science works in practice. On the contrary, it may be viewed as building on these influential conceptions of scientific literacy in what I take to be a crucial way, by adding and strongly emphasizing a very specific, philosophical understanding of what, precisely, science is, and what it is for. This understanding focuses on the capacity of the sciences, as our preeminent set of practices for complex problem solving, to allow us to *do* things successfully—yes, to help us fathom how subatomic particles interact and how galaxies form, but also to create vaccines that save lives, to produce more nutritious foods that enhance our wellbeing, and to make machines that allow us to see and communicate with loved ones the world over. This is by far the most important ingredient in any conception of literacy relating to the sciences that stands a realistic hope of bolstering support for the use of our best science in acting for the common good, or so I will contend.

2 Challenges to Deploying Science: Public Understanding

For present purposes, let us distinguish between what I will call *intrinsic* and *extrinsic* challenges to public understandings of science. The former derive from features of science itself, including both scientific practices and the outputs of scientific investigation, such as theories and models, that inevitably problematize the widespread understanding of science beyond certain specialist communities of scientists, students, and other experts. The latter derive from strictly extra-scientific interventions in both scientific work and the reception of the outputs of this work by non-experts. By undermining public understanding in various ways, both intrinsic and extrinsic challenges function as powerful impediments to widespread support for science-based policy and governance. While I will focus primarily on intrinsic challenges here, the morals of this discussion are nonetheless relevant to confronting extrinsic challenges as well. Thus, let me clarify this distinction briefly, which may be useful in subsequent sections for thinking about how to combat these challenges across the board.

The notion of intrinsic challenges to public understanding is familiar. As in any specialist endeavor, in order to engage with subject matters in depth and with the requisite precision, the sciences employ technical terms and concepts, often elaborated by means of highly sophisticated mathematical, statistical, computational, and other tools of description and analysis, none of which can be reasonably expected to make much if any sense at all to anyone lacking the immersive training that mastering these languages and tools requires for understanding. Indeed, as in many branches of study, degrees of sub-specialization within the sciences have rendered many areas of research effectively inaccessible even to other scientists working within the same broad disciplines. It is hardly surprising, then, that the intrinsic complexities of specific phenomena of interest, tools of investigation and description, and resulting theories and models are, for the most part, opaque to non-experts, from which stems a series of challenges to public understanding—intrinsic challenges. The severity of these challenges is evidenced, for example, in the highly variable nature of science reporting (in newspapers, magazines, online platforms, etc.), where a lack of attention to or misunderstandings of the intrinsic complexities of science are not uncommon.[2]

Perhaps less obvious, but posing a no less formidable difficulty, impediments to public understanding stemming from extrinsic interventions have attracted significant attention in recent years in response to cases in which powerful individuals, social and political organizations, and corporations have attempted to subvert scientific knowledge that would otherwise compromise the pursuit of their own social, political, and economic interests. A growing body of history, philosophy, and sociology of science has documented cases in which science has been corrupted at the source—for example, by the funding of specific research programs by investors interested in generating certain results—or undermined by misrepresentations of scientific work, publicized to serve ideological interests whose pursuit might be otherwise derailed by our best science. Examples abound, from funding effects induced by tobacco and pharmaceutical companies, to campaigns aimed at misrepresenting climate science by the fossil fuel industry, to misinformation about the risks of potential side effects disseminated by anti-vaccine movements.[3] Similarly, advocates of pseudoscience—claims or systems of belief or practice that masquerade as exemplifying the methodological rigor of science (astrology, homeopathy, parapsychology, etc.)—may disrupt public understandings of genuine science, even if that is not their intention.

Having made the distinction between intrinsic and extrinsic challenges to public understanding, it is easy to see why suggestions for wrestling with the latter so often take the form of calls to wrestle with the former. No doubt, pointing to surprising “coincidences” in which research funded by interested parties produces results that are beneficial to those parties, or cases in which lobbyists for certain ideological positions just happen to come equipped with “their own results” in support of their causes, may be sufficient to raise suspicion (if not thoroughgoing skepticism) about such claims. But in many cases, in order to make criticisms of extrinsic interventions stick, it is helpful to demonstrate their epistemic failings in more detailed ways, and this amounts to demonstrating how misrepresentations of science, and pseudoscience, fall short of the standards of genuine science, which requires overcoming intrinsic challenges to public understanding. Furthermore, raising suspicions about extrinsic intervention is only half the battle. It is not, all by itself, sufficient to raise confidence in the *alternative*, namely, our best science, as something that is worthy of support and inclusion in discussions of policy and governance instead. Either way, it is clear that much depends on overcoming intrinsic challenges to public understanding, and this is where I turn next.

3 Enhancing Scientific Literacy: Good News and Bad News

Understanding in this context requires degrees of comprehension or mastery that cannot be had without an education (whether formal or informal and to what extents are questions I will leave open here). On this much, educators agree, but what should be the content this education? I submit that in recent decades, two answers to this question have been

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[2] See Norris and Phillips (2003), for instance, for a summary of the failings of much science journalism to communicate scientific information correctly.

[3] For just a few recent studies, see Krimsky (2004), Brown (2008), and Oreskes and Conway (2010).

especially prominent. In more abstract terms, one may describe both of them as advocating for greater scientific literacy. More concretely, however, the first conceives of literacy in a relatively narrow way, and the second in a substantially broader way. These two approaches to scientific understanding—scientific literacy construed narrowly and broadly—correspond to what I earlier called "scientific knowledge" and "knowledge of science," respectively, and there can be no question that both of these forms of knowledge are valuable and inherently desirable. Nonetheless, I will argue next that, at least so far as the task of improving the public understanding of science is concerned, neither has been conceived in a way that is likely to lead to success. Let us take each in turn.

Scientific literacy narrowly construed is concerned with scientific knowledge: the descriptive content of our best theories and models and the skills and concepts required to understand this content. Norris and Philips (2009, p. 271) describe this as the "fundamental sense" of scientific literacy—emphasizing the ability to read and write science itself—and contend that if a scientific education does not provide this, it "is not likely to achieve the good for citizens and society that we all desire" (p. 282).[4] Here we have a direct connection drawn between what is undoubtedly a well-entrenched, dictionary-definition-type rendering of "literacy," in terms of the competent execution of reading and writing, and positive consequences for public understanding. And as these authors and many others have rightly noted, understanding the descriptive content of science and possessing the sorts of skills and concepts that may facilitate this, such as the ability to understand the relevance of data and analysis, degrees of confidence in reported findings, and various devices in terms of which these things are expressed, such as graphs and diagrams, would certainly amount to level of understanding that would surely favor the use of at least some of our best science in acting for the good of society. So far as it goes, this is the good news about scientific literacy narrowly construed.

The bad news, however, is that as a means to the end of widespread understanding, achieving sufficiently highly distributed levels of this sort of literacy is utopian. To think that we could achieve widespread scientific understanding this way is to gloss over the complexities of modern science and the standards of education required to achieve this sort of proficiency. I have already mentioned a number of intrinsic challenges, including the use of technical concepts and advanced mathematics, and the fact that these things do not simply comprise a manageable suite of tools that can be learned once and then applied across the sciences, but are rather, often, highly idiosyncratic to the very specific subdisciplines in which they are used. Add to this scientific techniques of abstraction, in which causally relevant parameters used to investigate target phenomena are parsed in different ways for different purposes, and the routine use of idealizations, in which aspects of these targets are represented in ways that scientists know them *not* to be, for reasons of mathematical or computational tractability, and the ubiquity of approximations, and implicit understandings within fields regarding how well established or conjectural current theorizing may be—all of which, again, is highly contextual across different subdomains of physics, chemistry, biology, and the social sciences, let alone science *simpliciter*.

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[4] Norris and Phillips (2009), pp. 271–273, contrast this "fundamental sense," which they advocate, with a "derived sense," which concerns "the substantive content of science." It is difficult to imagine exemplifying the former without also exemplifying a good deal of what falls under the latter, but in any case, as I will argue below, both are problematic for present purposes. Feinstein et al. (2013), p. 314, offer partially overlapping advice for "cultivating competent [scientific] outsiders." For a sweeping review of historical and conceptual approaches to scientific literacy, see Laugksch (2000).

None of this is to suggest that scientific literacy narrowly construed is not worth promoting, on the contrary. That said, in practice, it is highly unrealistic to imagine that in connection with our best, cutting-edge investigations into the most pressing issues of our day—genetic modification, climate change, artificial intelligence, etc.—this sort of literacy is something that could be inculcated in a majority of citizens. It requires a specialized education over significant durations of time and, as noted above, not even scientists are capable of this sort of literacy across the vast breadth of the sciences. Indeed, the impracticability of achieving widespread levels of scientific literacy narrowly construed is much more severe than even this suggests, because (of course) the sciences do not stand still. Whatever non-specialists acquire today will inevitably be modified and replaced over time as technical concepts, forms of data collection and analysis, and so on evolve. Scientific literacy narrowly construed is a good thing, but it will never serve as the primary basis of a widespread public understanding.

Let us turn, then, to a second prominent conception of scientific literacy, which has likewise come to the fore in recent decades. What I have called scientific literacy *broadly* construed is less concerned with (reading and writing) scientific knowledge per se, and more concerned with a knowledge *of* science, that is, of science conceived more generally as a practice or set of practices of investigation and knowledge generation. This, too, is undoubtedly a good thing: the extraordinary cultural significance and impact of forms of scientific inquiry in modern times is difficult to overstate, and the greater the extent to which members of societies, which unavoidably partake in and are affected by the sciences, are educated with respect to these nuances, the better. As I will now suggest, however, scientific literacy broadly construed—at least as it has been conceived in recent times—has little potential to serve as the primary basis of a public understanding of science that supports its inclusion in decision making for the common good.

First, let us clarify what a knowledge of science or "the nature of science" is, more precisely. Identifying it with scientific practices (as opposed to the descriptive content of theories and models) is a start, but a great deal hangs on what is included under this heading. For example, does it include techniques of investigation—the use of instruments and other technologies in observation, detection, measurement, and data collection? How about techniques of analysis—the use of mathematics, statistics, computations such as computer simulations, and other procedures involved in moving from data to conclusions? The methods of science are surely part of its nature, but as is suggested by their partial overlap with items whose understanding would be required to achieve scientific literacy *narrowly* construed, including scientific methods in a conception of literacy *broadly* construed is likewise a nonstarter for enhancing public understanding. All of the same concerns apply: scientific methods are intricate and complex; their mastery requires substantial training over significant periods of time; they vary remarkably across scientific disciplines and subdisciplines; and they are apt to evolve and change over time as the science develops. As such, for reasons already covered, the methods of science cannot plausibly be considered an effective cornerstone of efforts to achieve widespread public understanding.

Perhaps appreciating this, some appeals to scientific literacy broadly construed take a different tack. They appeal, in various ways, to features of the sciences that are the primary focus of the scholarly field of history and philosophy of science (HPS, which I will take here to include closely integrated disciplines including the sociology of science and ethnographic, anthropological, and related modes of research commonly employed in the field of Science Studies more generally).[5] These appeals have in common the contention that incorporating HPS into science curricula would be a good thing, but as a whole, I submit, it is difficult to discern in them a positive case for thinking that this is so. Often, the driving, underlying intimation appears to be the suggestion that insights from HPS would instill the view that the sciences are epistemically virtuous in certain ways: rational; objective; reliable producers of knowledge; and so on. This is belied, however, by the very morals that this literature commonly identifies as emanating from scholarship in HPS. Let me illustrate this no doubt provocative claim with just a few examples.

Ennis (1979) advocates integrating a number of "results" stemming from research in HPS with science education. These include the idea that scientific claims are often subject to "unmentioned qualifications" (pp. 151–152), that they are tentative and subject to revision (p. 152), and that they are sometimes vague and imprecise (p. 156). All of this is correct, of course, but absent a deeper embedding of these facts into a systematic or more substantial account of the epistemology of science—something that scholars in HPS routinely attempt to provide, but that authors concerned with scientific literacy appear (rightly) to agree would be beyond the capacities of general science curricula as such—it is difficult to see how one might characterize these observations as indicative of the epistemic virtues of science, in a way that might then bolster widespread support for science-based policy and governance. Taken at face value, these observations might well seem more likely to encourage skepticism than to inspire confidence in scientific claims.

Similarly, in an extensive review of the literature, McComas et al. (1998, pp. 512–513) contend that while there is significant disagreement within HPS about the nature of science ("what science is and how it works"), there is, in fact, a consensus view regarding aspects that are "most important for a scientifically literate society," thus constituting "fundamental issues in the nature of science relevant to science education." From their list of fourteen bullet points comprising this consensus, however, there is very little that might support the idea that science is something that should inform decision making in the public domain. Some of the points are epistemically neutral (e.g., "Scientists are creative"; "Science is part of social and cultural traditions"), and others might easily engender skepticism about passing references to "experimental evidence" and "rational arguments" (e.g., "Observations are theory-laden"; "Scientific ideas are affected by their social and historical milieu"). Once again, the point here is not that any of this is incorrect, nor is it that there can be no mitigation of what might otherwise appear to be worrying features of science regarding the likelihood of it being trustworthy. Rather, it is that giving an account of scientific knowledge that achieves this more detailed understanding would require a much fuller and more subtle engagement with scholarship in HPS than is practicable in a general science education.

Consider, for example, the notion that scientific thinking is, in various ways that have been elaborated through case studies in HPS, responsive to social and historical influences. Leaving aside for the moment the fact that the ways and extents to which this is the case, and the epistemic consequences, are disputed within the field, the basic idea is widely accepted. That said, the fact that social and historical context may affect the formulation and development of scientific hypotheses, theories, and models does not by itself

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[5] Hence the literature in recent decades aiming to introduce educators to this realm of scholarship, in hopes of facilitating the cause of scientific literacy. See, for example, Martin (1985/1972), Ennis (1979), McComas et al., and Matthews (2015).

suggest anything about the nature of science that should bolster confidence in the prospects of science-based policy in pursuit of the common good. Lacking expert knowledge that may allow one to determine whether such policy is, in fact, desirable—whether the influence of a given social or historical context is a good thing or bad—a general, skeptical attitude hardly seems unreasonable. The same may be said of other items of bullet point consensus, such as the notion that observations are theory laden; that is, that the way scientists describe the data of observation and experimental detection is influenced by the very hypotheses or theories these data are meant to test. Questions about the ways and extents to which this occurs, and whether it is, in fact, a good thing or bad, cannot be answered except through an application of much more fulsome expertise than a general science education can instill.

Indeed, the bad news for scientific literacy broadly construed, at least insofar as one might imagine it to be a means to the end of greater public understanding, is quite a bit worse than this last consideration suggests. It is not merely the case that abstracting certain facts about scientific practice from the nuanced understandings of them elaborated in the scholarly discipline of HPS cannot serve to facilitate public understanding, due to the impracticability of de-abstracting. It is furthermore that there is, as noted above, deep disagreement *within* HPS about how these facts should be understood, concretely. Does science produce knowledge? If so, what sort? Do social dimensions of science help or hinder this production? How so and with what consequences? There are longstanding and highly articulated debates here, and no settled consensus regarding how best to think about the epistemic status of our best science. This exposes the fragility of McComas et al.'s claim (1998, p. 512) that "the issues included in the following table [of consensus bullet points] are complex, but we are making recommendations for K-12 students and their teachers – not future philosophers of science." The putative consensus underwriting scientific literacy broadly construed is a sham, built on a foundation of conflicting views in HPS regarding how these issues should be understood.[6] This is far from a promising basis for an education with which to facilitate public understanding in the service of the common good.

4 Conditions Underpinning Successful Knowledge Transfer

Even if scientific literacy narrowly and/or broadly construed were to end up featuring as aspects of a compelling account of scientific literacy *simpliciter*, for reasons we have just considered, something more—or something else—is required if we are to enhance public understanding. Thus, we arrive at the question of what this something else may be. In order to tackle this question systematically, let me first step back to consider certain conditions that seem essential to realizing the goal of improving levels of public understanding, and why in the absence of these conditions, success in this endeavor is not something we should expect. To this end, let us take a moment to reflect on the more general phenomenon of attempting to extract knowledge from one domain, and then employ it, effectively, in another. In doing this, we stand to gain clearer insight into why attempts to implement the conceptions of scientific literacy discussed above are unlikely to succeed in realizing the aim of greater public understanding, and thereby, the aim of greater support

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[6] I will return to this point in more detail in Section 5.

for science-based policy and governance. At the same time, we may lay the groundwork for an approach to scientific understanding that fares better.

In recent years, growing interest in the philosophy of science has targeted the idea of what is now commonly referred to as "knowledge transfer," especially in the context of scientific modeling. In a nutshell, the phenomenon of interest is that of how knowledge sometimes "travels" from a context in which it originates into a different one altogether. The sciences are replete with examples of how theorizing or modeling developed in one domain of research sometimes ends up finding its way into others, where it is likewise employed highly effectively. Models developed in game theory, for instance—the mathematical study of interactions between the choices of agents in decision making, with obvious applications to target phenomena in the social sciences—were subsequently applied with striking success in evolutionary biology. Models developed in the domain of physics have been adopted in the domain of economics, and so on.[7] Abstracting from the historical richness of these cases, the basic idea is to consider the extraction of some descriptive content that functions well in one domain, and its subsequent adoption in a separate domain in which it is also functions well, facilitating the achievement of whatever goals it may be employed to serve in each.

In scientific cases, though the subject matters at issue in the relevant domains, namely, the target systems under investigation *in* those domains, are different, there is nonetheless something in the descriptions of them that is shared. That is to say that there is some analogy or similarity between them that underlies the success of the transfer. Often, this is a formal or structural similarity: some set of relations between the relevant parameters in a mathematical, computational, causal, or other description. Transfers succeed, when they do, because even though the *semantics* of a given structure—its meaning in application to its subject matter—may vary between different contexts of use, it is nonetheless successfully interpretable in each. As an illustration of this, consider the Lotka-Volterra model, essentially a pair of coupled, non-linear differential equations, used in the context of ecology to describe fluctuations in populations of predator and prey organisms. While these equations are interpreted in the context of ecology *this* way, the very same model can *also* be used to describe economic fluctuations in employment rates and the share of labor in national income. In other words, it can be interpreted in the very different context of economics so as to serve a very different purpose.[8]

Here is the upshot for present purposes: what allows for the transfer of knowledge from one domain into another is the possibility of interpreting it successfully in those disparate contexts. The Lotka-Volterra model, taken as a mathematical description, can be successfully embedded in both ecological and economic contexts of interpretation *because* both of these domains feature conceptual and linguistic resources that allow the model to be successfully interpreted. Appropriate semantic embeddings are a necessary condition for the success of the knowledge transfer. Now, with this much in hand, let us see if it is possible to generalize or extend this notion of knowledge transfer to the focus of our present discussion—the public understanding of science. Here, the interest is not in transferring knowledge between contexts of scientific practice, but rather in transfers between scientific contexts, on the one hand, and broader, public, or societal contexts, on the other. As I will now suggest, while these two scenarios are in one sense tantalizingly analogous, prospects

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[7] For a recent collection of case studies from across the breadth of the sciences (and further references), see Herfeld and Lisciandra (eds.) (2019).

[8] See Humphreys (2019), pp. 15–16, for more detail.

for replicating the success of knowledge transfer in the former are seriously undermined in the latter by a telling disanalogy.

First, the analogy. In both science-to-science cases and science-to-society cases, any attempt to transfer knowledge will involve some putatively shared content between the contexts comprising each end of the transfer process. This is the basis, after all, of the attempt. Focusing now on attempts to transfer knowledge between the scientific domains in which it is produced, and the public domain in which we hope to assimilate it, this content may be thought of in terms of putative facts—say, regarding the likely consequences of sustained anthropogenic contributions (at current levels) to climate change, or the efficacy and risk profile of vaccines developed in response to a pandemic. In other words, the content to be transferred takes the form of assertions regarding the epistemic upshot of theories and models: descriptive claims; explanatory claims; predictions; and retrodictions. But here, in all but the most simple cases, a disanalogy between attempts to perform science-to-science and science-to-society transfers is highly consequential. Transfers succeed in the former case because the domains at issue satisfy the necessary condition specified above: they each embed the relevant content in an interpretive context that has the capacity to produce an understanding of it that functions successfully.[9] In the latter case, however, for reasons intimated in the previous section (which I will now spell out), given currently prominent conceptions of scientific literacy, this condition is bound to be unsatisfied.

Why are attempts to produce more widespread public understanding of science by means of scientific literacy narrowly and broadly construed destined to fail? One may think of this in terms of two classes of challenges. The first arises within (or with respect to) the scientific domains from which knowledge transfer is intended to originate, and concerns the determination of what, exactly, should be transferred. Let us call these *translational challenges*, since they concern the difficult task faced by scientific experts of re-describing their own knowledge in ways that are accessible to non-experts. Conversely, on the receiving end of aspirations for science-to-society knowledge transfer, another class of challenges likewise arises in attempts to embed scientific knowledge in a very different semantic context of conceptual and linguistic resources. These *interpretational challenges* concern the difficult task faced by non-experts of understanding the relevant science. I suspect that it is now apparent why scientific literacy narrowly construed and scientific literacy broadly construed are both vulnerable to translational and interpretational challenges. The discussion of Section 3 furnishes a catalogue of reasons for thinking this, but let me drive the point home with a concrete example.

Experts in specific domains of scientific inquiry—scientists themselves, historians and philosophers of science, science journalists, etc.—typically possess a mastery of the semantic contexts in which that science unfolds, allowing them to understand the content of theories and models expressed in their original form. (Levels of expertise vary, of course; let us assume a level corresponding, at a minimum, to this sort of mastery.[10]) Now, consider the task of an expert attempting to communicate this content to non-experts in the public sphere. In order to engage with non-experts who, by definition, lack mastery, a

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[9] Morgan (2014) outlines a number of generic strategies that scientists in different domains use to achieve this, given the conceptual and linguistic richness of their respective contexts of work.

[10] This excludes many to whom we might otherwise hope to attribute expertise. For instance, in a sobering study, Norris and Phillips (1994) document the failure of top, senior secondary school science students to interpret correctly the contents of (even) popular science reporting, systematically overestimating expressed degrees of certainty and failing to grasp basic forms of expression, such as causal claims (pp. 959–961).

translation that does justice to the content of the science is required, but how is this to be achieved? On the one hand, expressing this content in a way that conforms too strictly to the complexities and qualifications of scientific work runs headlong into interpretational challenges; such descriptions are unlikely to produce understanding in an audience that is incapable of embedding it in their own semantic context. On the other hand, straying too far from these nuances—in other words, employing simplified descriptions—produces claims that are often, strictly speaking, false. Even with the best will in the world, it is often impossible to overcome the translational challenges of simplifying sufficiently to generate non-expert understanding, while simultaneously communicating sufficient detail to avoid caricaturing the science.

A familiar example may serve to clarify this sort of interplay between translational and interpretational challenges. Secondary education in many parts of the world teaches that the sciences employ an especially effective procedure for investigating their subject matters—"the scientific method." This method is epistemically privileged: in inquiring into the natures of things of scientific interest, it functions as something like a procedural guide or recipe for generating truths. In reality, though, the idea of "a method" is an abstraction from some very specific forms of scientific inquiry, namely, those found in experimental disciplines. There are in fact many different forms of scientific investigation, and only some of them can be made to fit this particular mold. As it turns out, then, there is *no one* method. Upon examining the amazing variety of practices falling under the heading of "the sciences", from mapping the stages of stellar evolution, to exploring the ranges of animal behavior, to modeling quantum gravity, we find that there is no recipe amounting to a common procedure (barring desperate characterizations rendered largely uninformative by generalizing in the extreme: "science is empirical"; "science relies on evidence"; etc.).[11]

Translating the remarkable scope of scientific methods into the perhaps inspiring but nonetheless grossly caricatured notion of "the scientific method" fails in part because, as an indicator of what is required in order to be genuinely scientific—a defining feature of science, as it were—it is false. One consequence of this is that it opens the door to what I earlier described as extrinsic intervention by agents who seek to undermine scientific knowledge, by allowing them to raise doubts about branches of science that may not be well described by the caricature. Owing to the difficulties that undermine prospects for enhancing levels of scientific literacy narrowly and broadly construed, noted above, neither represents a promising antidote to such skepticism. The range and complexity of scientific methods, and the fact that much like theories and models, they too evolve over time (consider, for example, the dramatic methodological impact of the advent of computer simulations and, more recently, machine learning), returns us once again to prior concerns about the futility of attempting to promote widespread understanding through training in skills of reading and writing, or through an appreciation of the lessons of HPS. In the public domain, lacking the semantic context required to grasp the probative force of most scientific methods let alone all of them, interpretational challenges abound.

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[11] Cf. McComas et al.'s (1998, p. 513) third consensus bullet point: "There is no one way to do science (therefore, there is no universal step-by-step scientific method)." For a sample of the now vast philosophical scholarship on this point, see Crombie (1994), Hacking (1993), and Kwa (2011). See also Windschitl et al. (2008).

5 Philosophical Literacy Concerning the Nature of Science

In his reflections on education, Dewey (1916, p. 126) makes a passing reference to what I have described here as the contextuality of understanding in cases of aspirational knowledge transfer:

> Even the circle, square, etc., of geometry exhibit a difference from the squares and circles of familiar acquaintance, and the further one proceeds in mathematical science the greater the remoteness from the everyday empirical thing. In one case, as in the other, the meaning, or intellectual content, is what the element accomplishes in the system of which it is a member.

And yet, as he goes on to suggest, the concerns of everyday life and the interactions with the world these concerns provoke and inspire in us are not as disconnected from scientific thinking as this quotation may suggest. Scientific conceptions of the subject matters of science and related spheres of scientific activity are generally *about* things of concern to life beyond the sciences; and thus, the former are connected to the latter (Dewey, 1948, pp. 197–206). In this lies a glimpse of what I take to be a way forward in thinking about the public understanding of science, in a way that stands a better chance (than some we have considered) of realizing the goal of a more widespread appreciation for scientific knowledge—one that recognizes the importance and, indeed, the necessity of including our best science in acting in ways that promote our own welfare and that of society. The project of articulating this proposal in detail is one that exceeds my capacities here, but in closing, let me take some initial and I hope productive steps toward describing how we might envision it.

Earlier, I problematized the idea that scientific literacy broadly construed, as it is typically conceived, may serve as a means by which to enhance levels of public understanding. This conception of literacy, recall, is one that emphasizes an imagined, underlying consensus regarding the nature of science revealed by an examination of the history and philosophy of science. The difficulty with this, I argued, is that the elements of this supposed consensus, taken together, may naturally lead to substantial ambivalence or even skepticism about the epistemic status of scientific theories and models. Furthermore, while possibilities for a deeper analysis capable of resolving this ambivalence or skepticism are thoroughly discussed in the field of HPS, it is precisely this level of engagement and understanding that is (rightly) *not* conceived by proponents of scientific literacy broadly construed as a practicable component of non-expert education. Worst of all, in HPS, there is in fact extensive disagreement about how precisely the elements of this imagined consensus should be understood, and about the consequences they have for the status of scientific knowledge. In all of this, however, as I will now suggest in a more constructive vein, the difficulty with the "nature of science" approach is ultimately one of execution. It turns out that there *is* something to the idea of consensus here after all, but in order for it to do the work for which it is intended, it will have to be conceived in a very different way.

To elaborate this, let us start with a maximally general, epistemological question about the sciences: what is the upshot of our best science, in terms of knowledge? The answer to this question is hugely contested by philosophers of science. Scientific realists of various kinds take theories and models to describe correctly (or to some impressive degrees) aspects of a mind-independent world, but in different and conflicting ways; some antirealists assert similar-sounding claims regarding descriptions that meet certain, specified standards of success, but reject the idea that these descriptions and the things they describe are, in any intelligible way, independent of human ways of conceiving and knowing about them; others restrict the scope of what is known to that which is detectable, or to that which is detectable using human sensory modalities alone; and so on. Collectively, these positions reflect numerous disagreements about how best to understand the epistemic upshot of the sciences. And while there is no question that all of the proponents of these views would contend that our best science yields knowledge conceived one way or other, they differ enormously regarding what this knowledge is knowledge *of*, exactly.[12]

In the cut and thrust of now highly elaborated disputes between advocates of different epistemologies of science however—and almost invisible as a shared, background assumption, regarded in this domain as something of a banality underwriting further more detailed thinking about science—is a matter of genuine consensus. All scholars of the sciences, whatever their contrasting accounts of the nature of scientific knowledge may be, endorse the view that the sciences are instrumentally successful: they embody the very best techniques we have managed to establish, and continue to develop, for making predictions, for manipulating things and their properties, for intervening in events and processes, for changing states of affairs, and for applying all of the descriptions, explanations, instruments, and technologies we have fashioned in the course of scientific practice to tackle the problems and puzzles that confront us, and those we set for ourselves. Indeed, whatever else they may achieve, as described in more rarefied epistemological terms and disputed by experts, the sciences are *astonishingly* instrumentally successful. They incorporate practices that are specifically designed to be, and are selected as, our most successful strategies for delivering empirical success. In these terms, the sciences are supremely fixated on what works.[13]

The instrumental success of science, in all of these respects, is its one truly consensus feature. Viewed in this light, it is revealed not as a banal, background assumption of more interesting debates, but as a stunning achievement of human ingenuity and culture. Scholars differ in how they *explain* this success (in all of the ways noted above, for example, in terms of realist and antirealist descriptions of scientific knowledge), and these differences are, no doubt, philosophically interesting and worthy of debate. It is a consequential mistake, however, to allow this to obscure the more fundamental, underlying agreement. It is this agreement that should be at the heart of a promising, public understanding of science, and the focus of a general science education. There is an important story to be told here, I submit, regarding how, independently of the many differences in expert diagnoses of the nature of scientific knowledge, all of them recognize the same capacities of the sciences for acting in the world—and thus, by extension, for promoting the common good. There is a shared and powerful conception here of what the sciences are, and what they can achieve, functioning collectively in the manner of an extraordinary machine for generating our best hopes for responding to challenges inherent in our natural and social environments.

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[12] For extensive surveys of different forms of scientific realism and antirealism, with references to contemporary discussions and historical antecedents, see Chakravartty (2017/2011), Liston (2016), and Rowbottom (2019). Though I will not defend the assertion here, it seems clear that these positions reflect disagreements not merely among philosophers, but also, often, between scientists, especially in more speculative and cutting-edge domains of science.

[13] It should be clear from this characterization of instrumentally successful science that it applies across the ostensible distinction between "pure" and "applied" science—a distinction that is, in any case, often difficult to maintain in practice given the intimate connections between, and the interwoven nature of, the pure and the applied.

It is in the nature of a community of specialists to focus on matters about which they disagree, and then to imagine that these issues exhaust all of what is interesting or important about their specialism. In thinking about the public understanding of science, though, and about what conception of scientific literacy might support the practicable achievement of a widespread understanding that favors a central role for science in acting to serve the good of society, it is now past time to focus on the easily overlooked question of what we mean, or should mean, by "the success of science"—to articulate more clearly and fully the shared part of our many diverse understandings of science, on which our conflicting interpretations of the epistemic upshot of the sciences depend. While I regard the preceding as supplying ample motivation for this positive project, I cannot do it full justice here. That said, it is worth noting that when, hopefully, an increasing number of educators and scholar are ready to engage with this project in earnest, we will have the benefit of a head start furnished by earlier, embryonic articulations of it in the recent history of philosophy.

Consider, for example, the broad sweep of logical empiricism, associated with the birth of the philosophy of science as a self-aware subdiscipline of philosophy in the early twentieth century. Many of its core commitments have since been rejected, but for present purposes, there is something of substantial value to be recovered from its original motivations. The logical empiricists were keen to establish the sciences as *the* exemplary means by which to produce knowledge of the world, not (primarily) for its own sake, but because they took properly scientific knowledge to be the best possible means by which to facilitate social and moral progress. At the same time, when the American Pragmatists promoted the idea that concepts such as truth and knowledge must be understood as having a pragmatic dimension—that what it *is* for a claim to be meaningful must be understood, in part, on the basis of what we can *do* with it—they were articulating a view of how the sciences are tied to practical consequences in human experience.[14] In more rarefied debates about the nature of scientific knowledge, empiricism and pragmatism are often identified with the antirealist side of the ledger; in different ways, they resist traditional realist understandings of science as furnishing knowledge of a mind-independent world. Once again, however, this simply distracts from what is key to a potentially potent conception of the public understanding of science. Everyone, whether or not they think that the sciences are *merely* instrumentally effective, thinks that they *are* instrumentally effective.

The notion that it is part of the essence of the modern sciences to serve as a preeminent collection of instruments with which to face our most pressing challenges is compatible with further elaborations of their aims and achievements, but it is the instrumental piece that is crucial for the public understanding of science—and more specifically, for the sort of widespread public understanding that would support the pursuit of science-based policy and governance. As it requires no specialist knowledge or background to comprehend, this understanding is immune to the debilitating effects of translational and interpretational challenges that inevitably undermine current attempts to transfer scientific knowledge into the public domain. Of course, this does not preclude supplementation by scientific literacy both narrowly and broadly construed, to whatever extent this may be possible. Ultimately, however, what is crucial is something much simpler, more easily absorbed, and longer

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[14] The relationship between Dewey's "instrumentalist conception of science," for instance, and his views on science education, are explored in Waddington and Feinstein (2016). I should note that the inspiration I take from Dewey in this paper stems from aspects of the former that are strictly independent of (though connectable to, of course) his advocacy of social, activity-based, experiential learning in schools, in line with theories of experiential and progressive childhood education.

lasting: a more basic understanding of the functional role of science in society, as our most effective means to desirable ends for people and the planet. This is a cultural fact *about* science, about its intended place in the broad sphere of human endeavor and its staggering success therein, as opposed to a scientific fact *per se*, and its articulation and mastery thus counts as a form of philosophical literacy, however modest, regarding the nature of science.

6 Conclusions

This proposal, to shift the focus of a general science education from scientific literacy narrowly or broadly construed to a core notion of instrumental success, is both conciliatory and revolutionary. It is conciliatory in that, as noted above, it is not incompatible with current hopes of promoting literacy, whether narrowly in terms of skills and concepts required to engage with scientific work, or more broadly in terms of historical, philosophical, sociological, and other approaches to understanding the sciences that inform scholarship in HPS. Surely, the more students learn about all of this, the better. The proposed shift in focus is revolutionary, however, in suggesting that whatever a general science education may confer along the lines of scientific literacy narrowly and broadly construed, this should be viewed as a means to the end of instilling the more crucial idea that the sciences represent our best hopes for making positive change. For all of the reasons rehearsed above, teaching science itself and attention to scientific literacy simply cannot fulfill the aspiration of enhancing widespread support for science-based policy and governance. What this teaching and attention can do, however, is provide compelling evidence—a proof of concept, as it were—for the more foundational idea that the sciences embody our most potent strategies for instrumental success. This is precisely the knowledge we can and must transfer from the realm of the sciences into the public domain.

One might expect a number of beneficial consequences to follow from a widespread understanding of this simple idea. The entrenchment of it would promote a more extensive recognition, for example, of the fact that a preponderance of scientific consensus is generally our best bet for rational decision making in the present, even when that consensus is partial and apt for revision. It would promote the superior credentials of science over pseudoscience. Perhaps most importantly, given the tight connection between ambitions for instrumental success and the specific problems targeted by those ambitions, it would help us to think more transparently about *which* problems and *whose* problems are addressed by science, thus laying bare the deeply value-laden nature of scientific work and facilitating more explicit considerations of what we as a society *want* science to achieve, and for whom.[15] This would promote a welcome scrutiny and critique of extant values in science, thus contributing to the process of making it better, and more trenchant rejections of extrinsic interventions that seek to undermine the sciences to the detriment of the common good. It suggests a role not only for teachers, in reframing their approach to general science education, but also a role for experts in the sciences and humanities, in making the communication of this message the paramount objective of a broader scientific education for society as a whole.

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[15] In recent decades, these themes have been especially prominent in feminist philosophy of science. For some influential contributions to this burgeoning research, see Harding (1991), Longino (1990), and Kourany (2010).

Granted, these are lofty ambitions for an articulation of a basic form of philosophical literacy concerning the instrumental success of science, and the preceding discussion is hardly a panacea for all of the challenges associated with the uptake of scientific knowledge in the public domain. What people believe is a function not only of information made available to them, but of so many things in addition—their background beliefs and cognitive predispositions (conscious and unconscious), their social and institutional relationships, and much more besides. A clear understanding of what would constitute a genuinely efficacious public understanding of science is just one piece of this puzzle. It is, nevertheless, an essential piece, and one whose contours I hope the preceding has helped to illuminate.

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