Understanding the Progress of Science

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> The central problem of epistemology has always been and still is the problem of the growth of knowledge. *And the growth of knowledge can be studied best by studying the growth of scientific knowledge*.
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> —(Popper, 2002b, xix)

> Merely fact-minded sciences make merely fact-minded people.
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> —(Husserl, 1970, 6)

The growth of human knowledge is realized most dramatically in the growth of scientific knowledge. What we have come to know through science about the workings of our human bodies and the workings of heavenly bodies, among much else, astounds, especially in comparison to our accumulating knowledge of the commonplace and everyday. Impressed by the evident epistemic progress made by science, many philosophers during the 20th century thought that studying how scientific knowledge increases is a crucial task of epistemological inquiry, and, indeed, the progress of science has been a topic of considerable interest. Yet, eventually, late in the century, attention waned and for the most part shifted to other tasks.

Recently, however, a provocative article by Bird has re-ignited philosophical interest in the topic of scientific progress (Bird, 2007). Bird criticizes what he takes to have been the most prominent accounts advanced in the 20th century and presses for what he views as a venerable but lately overlooked one. He claims that realist philosophers of science have often presumed that truth is the goal of science and progress to be properly characterized by an accumulation of truth or truths, and notes that anti-realists have often rejected truth as a goal of science and characterized progress in terms of, among other things, "problem-solving effectiveness."[1] He criticizes the former for overlooking the relevance of justification to progress and the latter for giving up on truth. According to Bird it is knowledge that is properly the principal aim of science, such that science makes progress precisely when it shows the accumulation of scientific knowledge.

The ensuing discussion has raised several criticisms and generated modifications of Bird's view, most of which have come from supporters of (some version of) the truth-based account, although there have been supporters of Bird's general view that knowledge is the aim of science as well.[2] In general, the authors involved in this debate are avowed scientific realists, so they quickly dismiss anti-realism and, hence, the problem-solving approach, which they take to be untenable due to its assumed commitment to anti-realism.

In my view this attitude is unfortunate, for there is much of value in the problem-solving approach to characterizing scientific progress, much that is in fact independent of the realism/anti-realism debate in the philosophy of science.[3] Whatever the merits of the problem-solving approach, though, Bird does raise an important criticism of it when he argues that the approach lacks a clear epistemic goal. Indeed, the leading advocates, Thomas Kuhn and Larry Laudan, themselves explicitly reject characterizing problem-solving in traditional epistemic terms, for they reject the presuppositions of mainstream epistemology, especially those concerning truth and reference.

The landscape of epistemology has, however, changed significantly in the intervening years (that is, since the heyday of debates over scientific progress), such that it now seems possible to light an illuminating way which could guide the problem-solving approach towards the main streams of epistemological inquiry. My aim in this paper is to furnish a problem-solving-based characterization of the progress of science that addresses the lacuna identified by Bird, and I do this by taking understanding to be the principal epistemic aim of science.[4] While, on the face of

[1] Most famously (Kuhn, 1996) and (Laudan, 1977).

[2] A notable example of the former is (Niiniluoto, 2014); one of the latter is (Mizrahi, 2013).

[3] For more on scientific problems and problem-solving see especially (Nickles, 1981).

[4] The idea of connecting problem-solving and understanding in roughly this way was mooted already some time ago by Maurice Finocchiaro, although it was never developed or explored in any detail by anyone (Finocchiaro, 1975, 1981).

it, it is quite intuitive that the point of solving problems is to achieve a degree of understanding, the idea is able to receive a deeper philosophical explication thanks to recent developments in epistemology concerning the concept of understanding. Many of these developments have been in response to the value problem of knowledge, in the face of which philosophers have increasingly concluded that knowledge lacks a sufficiently distinctive value to deserve pride of place in epistemology, with several philosophers making compelling cases that it is in fact understanding which has the needed kind of distinctive value to make sense of our epistemic practices (Elgin, 1996; Zagzebski, 1996; Kvanvig, 2003; Riggs, 2003; Pritchard, 2010). Although I will not adopt any of their specific proposals here, I believe that the considerations which lead them to focus on understanding are importantly relevant to a proper characterization of progress in science and, in particular, fit well with the problem-solving accounts.

Observers of old and recent debates about scientific explanation and understanding will undoubtedly be aware that I am not alone in suggesting the relevance of understanding to the issue of scientific progress. Against this suggestion, of course, is also a long tradition in the philosophy of science to consider understanding as merely "psychological," starting with Hempel's influential studies of explanation (Hempel, 1965), through van Fraassen's pragmatic account of explanation (van Fraassen, 1980), and continuing up to the present in the work of Trout (2002). Other philosophers of science have nevertheless pressed the idea that understanding is an important product of science in motivating their own favored accounts of scientific explanation (without, however, showing precisely how explanation is related to understanding or even explaining what understanding is).[5] Perhaps unsurprisingly, given this history, some responses to Bird's recent arguments have also suggested taking understanding rather than knowledge as a goal.[6] However, it is needful to stress that they propose this move simply as a means to make progress harder to obtain, since progress on Bird's basic account is evidently much too easy, due mainly to the easy availability of trivial facts, hence progress.[7]

The important point to note for my purposes is that all of those who invoke understanding in response to Bird's arguments choose to interpret it as merely a matter of prediction or explanation, which makes it plausibly reducible to knowledge (or nearly so). In contrast, I follow many contemporary epistemologists in taking understanding to be a distinctive epistemological good, one that does not reduce to knowledge. I also characterize understanding in terms of ability.[8] The requisite ability is relative to a subject matter—specifically a scientific theory of some subject matter. Understanding a theory means, more specifically, having the ability to produce explanations and descriptions which pertain to the subject matter of that theory. It does not mean possessing a more or less complete stock of facts about that subject matter, for that is not a tenable view of what a theory is. Individual, atomistic items of knowledge (explanations and descriptions) furnished by an understanding of a theory are therefore not of primary epistemological importance; rather, they serve to indicate or develop an understanding, that state which has distinctive epistemic value to its possessor. It is thus that there is an intuitive connection between such a view of understanding and the problem solving approach to progress, since solving problems can naturally be seen as an indication of progress in terms of understanding.[9]

1. SCIENTIFIC REALISM AND THE AIMS OF SCIENCE

I will now proceed more systematically in developing a problem-solving account of scientific progress based on understanding, beginning with the notion of progress in science. Progress in general is made, intuitively, with respect to some goal or aim. Science, of course, is a complex enterprise, and its practitioners have diverse aims, from practical to aesthetic, from ethical to epistemic. One of the distinguishing features of science, however, is the high value placed on its epistemic aims. The epistemic goods of science not only substantially underwrite the satisfaction of its practical aims, but they are frequently thought to represent goods in their own right. Indeed, some sciences are pursued which evidently lack any much practical application at all, such as historical sciences like paleontology, cosmology, and historical linguistics. Thus, when one speaks of progress in science it is seemingly quite natural to interpret this as epistemic progress.

Yet, despite this evident importance of epistemic aims, most discussions in the philosophy of science concerning scientific progress have centered substantially on the thesis of scientific realism rather than the nature of epistemic goods. Due to the important role that truth plays in the realism debate, it is easy to conclude, as Bird does, that realists

[5]This latter charge is raised in particular by Kim (1994). See also (de Regt and Dieks, 2005).

[6]See, for example, (Dellsén, 2016) and (Bangu, 2017). Bird (2007) in fact also suggests that a modification like this is necessary.

[7]It is, for example, easy to measure innumerable grains of sand on the beach, but doing so hardly seems like making scientific progress.

[8]This view pressed in the philosophy of science in particular by de Regt (2017); de Regt and Dieks (2005).

[9]There are only few remarks in the literature linking understanding and problem-solving. de Regt and Dieks (2005, 154). Zagzebski (2001) too notes that a person who understands a subject matter is most likely a reliable problem solver.

conceive of truth itself as the principal goal of science. Thus one might say in this vein that scientists aim primarily to acquire ever more true beliefs about the world (and, presumably, avoid false ones). Influential anti-realist arguments, such as the pessimistic meta-induction, have, however, discouraged many philosophers from believing in a simple incremental accumulation in truths over time.[10] Hence realists generally conceive of progress in terms of an approach to truth, states on the way to which are sometimes characterized in terms of "truth-likeness" or "verisimilitude" (Popper, 2002a; Niiniluoto, 1980).

Anti-realist philosophers of science usually reject the realist's account of truth as an overly inflated or illegitimate aim of science and, insofar as they maintain the positivistic belief in the progress of science, seek to characterize progress in different terms. The empiricism of van Fraassen, for example, limits the epistemic aim of science to empirical adequacy (van Fraassen, 1980) He thereby preserves the referential core of the realist conception of truth in his account but restricts it to a privileged set of truths—the empirical truths. Other anti-realists are more radical in their dismissal of realist notions of truth, including those which describe progress in terms of problem-solving.[11] Bird groups these latter approaches under the heading "functional-internalist," for they characterize progress in terms of some function (problem-solving), which function is evaluable according to the internal standards of the relevant scientific community.

From an epistemological standpoint it might seem somewhat narrow-minded for debates on the progress of science to focus so much on truth, presumably at the expense of more properly epistemic notions like knowledge. Of course, epistemologists themselves do traditionally assume that truth is in one way or another essential to knowledge. Yet, at the same time, one notices that they usually do not question its nature too deeply, rather focusing their attention on the nature of knowledge and justification, their structure, their sources, etc. And, indeed, it is precisely because of its particular methods of justification that science is generally thought to be especially worthy of epistemological scrutiny. The importance of these methods makes it appear most natural, therefore, to conceive of scientific progress in epistemic terms rather than merely alethic ones.

It is essentially from this standpoint that Bird criticizes realist accounts of progress (which he collectively dubs the "semantic" view), alleging that by adopting truth as the aim of science they ignore the importance of justification and allied notions for science. If true belief alone were the aim of science and progress a matter of acquiring more true beliefs or approaching the truth, then it would be quite difficult to make sense of the practice of science, which involves much effort in insuring the reliability, robustness, justification, etc. of scientific beliefs. Nevertheless, with due respect to Bird, to criticize realists on these grounds is quite unfair, since scientific realists are fully aware of and accept the importance of justification in an account of progress and in science in general.[12] Thus, Bird's claim that "realists have typically sought an account of progress in terms of increasing verisimilitude (truth-likeness, approximate truth) rather than increasing knowledge" (Bird, 2007, 64) is misleading if not mistaken. It would be just as misleading to infer from the inclusion of truth as an essential component of knowledge that "epistemologists have typically sought an account of knowledge in terms of true belief rather than knowledge itself." In short, realist accounts of progress are epistemic accounts of progress. That they are characterized in terms of verisimilitude or truth rather than knowledge is best read as a matter of emphasis, which is due simply to the long-standing centrality of the realist debate in the philosophy of science.

If there is a difference between Bird's simple epistemic account of progress and a realist's, then it is a difference as to whether progress is cumulative. As said, the history of science has strongly suggested to most philosophers of science that progress is not incremental in truths, which is why realists prefer to appeal to notions of truth-likeness, rather than the accumulation of truths, when characterizing the progress of science. Bird does note this point and responds to it by pointing to a variety of long-standing scientific facts which we should not expect to become false in the future, for example that chemical substances are constituted by atoms. Yet this defense should be dubious in light of much 20th century philosophy of science, for the concepts used in these facts have surely not maintained their meaning through scientific revolutions, as Bird must assume for this to be a relevant riposte. To put it lightly, echoing a point of Putnam's, *you can't have your scientific revolution and minimize it too* (Putnam, 1967, 13).

So, although Bird's narrow-minded "semantic" account is a possible view to hold, it is not a view entertained within the philosophy of science. Bird and realist philosophers of science are in agreement that scientific progress is epistemic

[10] Important historical examples have been urged most prominently in (Feyerabend, 1975; Kuhn, 1996; Laudan, 1981, 1984).

[11] The main accounts, again, are found in (Kuhn, 1996; Laudan, 1977). Popper also also describes progress as fundamentally a matter of solving problems, albeit without sharing Kuhn and Laudan's anti-realist inclinations. Toulmin's approach also bears some affinities to the problem-solving approach. See (Popper, 2002a; Toulmin, 1972). I shall not discuss the latter two further, for Kuhn's and Laudan's views are the most relevant for my account.

[12] For statements to this effect, see (Niiniluoto, 2014) and (Saatsi, forthcoming).

progress and that truth is essential to it. Suitably qualified, certain anti-realists would account for progress in a similar way as well, for example, in terms of increase of empirical knowledge or approach to empirical adequacy. These accounts are, however, at odds with anti-realism of a different kind, the kind which Bird describes as "functionalist-internalist." Whereas Bird criticizes realists for allegedly ignoring the "justification" condition on knowledge, he criticizes the anti-realist "functional-internalists" for rejecting the "truth" condition on knowledge. He argues that if progress rests on the solution of puzzles and problems, as some anti-realists maintain, and those solutions do not have to be true (or even truth-like), then counting them as instances of progress strongly clashes with intuitions that one has made progress (Bird, 2007).

Such anti-realists are indeed skeptical of truth as understood by the realist, for they doubt that the methods of science are capable of securing it, and they believe that the history of science substantially bears that doubt out. Laudan, for example, maintains that realist accounts of progress are "*utopian*, in the literal sense that we can never know whether they are being achieved" (Laudan, 1977, 127). Kuhn paints the realist's truth as similarly unreachable, a "goal set by nature in advance" of our inquiry into it (Kuhn, 1996, 171). Instead they prefer to characterize progress in terms that can be assessed by reference to the historical development of science. Thus, Laudan founds his account of progress on the idea of increasing "problem-solving effectiveness"; Kuhn suggests that science's successes might better be understood by conceiving of progress "in terms of evolution from the community's state of knowledge at any given time"(Kuhn, 1996, 171).

Observe that both Laudan and Kuhn explicitly make reference to knowledge in the above quotations. Hark! Is this not incommensurable with their alleged rejection of truth? Well, of course, whether there is in fact a tension here turns on what they take truth to be and what they take knowledge to be. If one does reject the relevance of the realist's truth to scientific progress, then one might try to characterize knowledge just as what we take ourselves to know. This seems to be the case that troubles Bird, since the discrepancy between what we take ourselves to know and what we "actually know," so to speak, might be (and often enough is) quite substantial. Yet the realist account of truth and the notion that knowledge entails truth hardly exhausts the philosophical options. An anti-realist may reject the traditional account of truth adopted by realist philosophers of science, perhaps in favor of another account, such as a pragmatist, a coherentist, or some other theory of truth; one might then characterize knowledge in terms of this kind of truth. Rejecting the realist account of truth is not, then, necessarily grounds for dismissing the functional-internalist account of progress.

As it happens, Kuhn himself did think that truth was an important standard, even a necessary one, within the context of a paradigm—just not the utopian truth of the realist. But whatever Laudan's and Kuhn's views on truth and knowledge actually amount to (it is certainly not my brief to argue what they are here), the point I wish to stand on is that the philosophical debate over the nature of truth remains a controversial one, as all theories available face significant challenges. Just as the epistemologist accepts that truth is somehow essential to knowledge without entering into the thick of the debate over the nature of truth, so too an account of progress may allow that truth plays an important role in scientific progress, without presupposing any particular resolution of the debate over the nature of truth. Bracketing the issue of truth allows the epistemologist to get on with the business of inquiring about epistemology, at least until she is forced to take a stand one way or another by certain difficulties. It seems likewise reasonable to pursue, so far as one can, accounts of scientific progress which do not presuppose the outcome of the contentious debate over realism and the realist's notion of truth.[13]

Bird's and others' dismissal of the problem-solving approach therefore depends substantially on a particular kind of anti-realism that may be linked to it. Admittedly, the proponents of the approach have fostered such an interpretation due to their general philosophical views of science. Nevertheless, the problem-solving approach is not wedded to the wholesale rejection of epistemology, as Kuhn and Laudan themselves suggest by some of their remarks. Indeed, solving problems intuitively has some epistemic significance. As Bird rightly points out, though, the approach does lack a clear epistemic goal as it stands. All one finds in the work of Kuhn and Laudan are bland statements to the effect that problem-solving is "the single most general cognitive aim of science" (Laudan, 1977, 124) or that scientists solve puzzles because they simply like the challenge (Kuhn, 1996, xx). This leaves one with some work to do, if one is to assimilate the problem-solving account into epistemology. My task in the following will be to argue that taking the problem-solving approach's epistemic goal to be understanding can deliver on this goal, while offering a novel and distinctive epistemic account of scientific progress. By doing so, I aim to distinguish accounts of progress not by their realist or anti-realist credentials, as I have shown Bird's typology in effect does, but by an epistemically significant distinction between knowledge-based accounts and understanding-based accounts.

[13] It is worth mentioning that this is a significant motivation for Laudan himself, who pointedly does not rule out the realist conception of science (Laudan, 1977, 125).

2. UNDERSTANDING AS THE PRINCIPAL EPISTEMIC AIM OF SCIENCE

As remarked above, for the past century many philosophers of science have thought that understanding was too subjective to be a part of epistemology. Trout, in recent years the staunchest defender of this point of view, voices their concern when he maintains that understanding is only an individual, psychological phenomenon and hence not a proper subject matter for epistemology (Trout, 2002). While one can agree with Trout that there is a dimension of our concept of understanding along the lines he suggests, that does not preclude a sense of understanding which is appropriately objective, one which is a suitable object for epistemological study.[14]

Incidentally, this dispute over whether understanding is subjective or objective makes the case much like that of explanation, which in the decades prior to Hempel's influential work was also largely ignored by analytic philosophers on the grounds that it was too subjective. History has, of course, amply borne out the prospects of an objective notion of explanation; undoubtedly the same will be true of understanding, thanks especially to the work of several philosophers, mentioned above, in the last couple of decades to articulate an epistemology of understanding.

Against this tide of support for an epistemic notion of understanding, however, stand some who, while accepting that there is such a notion, believe that the new epistemology of understanding has added little to the long-established epistemology of knowledge. Several philosophers have argued that understanding reduces to (or merely is a species of) knowledge, especially explanatory knowledge.[15] If it were true that understanding really is essentially knowledge (at least for epistemological purposes), then the import of understanding would be minimal indeed.[16] I acknowledge that this is a central issue and so will address it in brief in the final section of this paper. There I will suggest a particular way of distinguishing knowledge and understanding, although my defense will be partial, since the aim of this paper is not principally to resist reductionism in this context. In any case, for now I will mostly rely on the intuition that these concepts are distinct in arguing that understanding is the principal epistemic aim of science.

I begin, owing particularly to the importance of explanations in science, with the observation that the distinctive locus of epistemic content in science is not the bare scientific fact; it is scientific theory. By theory I mean not only the conventional sense of it, namely theory which is general, abstract, involves laws, etc., but also to include other explanatory tools like scientific frameworks and models. Empiricist scruples may incline some towards the view that the epistemic content of science is not to be identified with scientific theory, but even the staunchest empiricist must admit that scientific theory is nonetheless indispensable for securing the greater part of those empirical facts which we do possess. So, in the case where scientific explanations are accepted as genuinely epistemic, theory is clearly the seat of epistemic value in science; but even when not, theory remains the primary vehicle of epistemic value in science (since theory is still crucial for obtaining empirical knowledge).

Now, as one can treat scientific theories as linguistic objects in epistemic locutions attributing understanding to an agent, one may, following Jonathan Kvanvig, characterize our understanding of scientific theories as objectual (Kvanvig, 2003). Although many philosophers have been willing to entertain the category of objectual understanding, it still remains unclear precisely how it should be analyzed.[17] Some authors, including Kvanvig, talk of the objects of objectual understanding as bodies of beliefs, while highlighting the coherence, holism, or integration of these beliefs as crucial for their status as objects. While I agree with proponents of objectual understanding that it is a distinct category of kinds of understanding and that understanding a theory can be described as a kind of objectual understanding, I will not follow them in holding that theories are best thought of as bodies of belief (for reasons to be explained shortly and also further in the final section). Besides, the category of objectual understanding is far too broad, for phenomena can be understood objectually as well as theory, yet theories and phenomena should clearly be epistemologically distinct categories, as it is theories that explain phenomena and not vice versa. Thus, I will avoid using the "objectual" terminology in what follows; instead I will speak of *theoretical understanding*.

One might think that there is not much of epistemological significance in the distinction between scientific facts and scientific theories. If scientific theories were merely collections of facts, then believing a theory would be nothing more than believing the relevant collection of propositions. I allow that, at least for some logical and epistemological purposes, treating theories as if they were such is sometimes fruitful and relatively harmless. Actual theories, however, the ones that scientists use, are surely not mere collections of facts. In the first place, it is suggestive that scientific theories are not learned as collections of facts and are not communicated as such either. Indeed, it seems plain that

[14] As de Regt argues in (de Regt, 2004). Trout replies in (Trout, 2005).

[15] A few notable examples of (at least partial) defenses of this view are (Grimm, 2006; Khalifa, 2012; Strevens, 2013).

[16] Although, as Kim (1994) argues, even in this case one would wish to see an account of precisely what knowledge (or how explanation) gives rise to understanding, something conspicuously lacking from most accounts of scientific explanation.

[17] For some discussion, see (Khalifa, 2013) and (Carter and Gordon, 2014).

the content of actual theories is incapable of being captured in such a simplistic way (in point of fact, not merely in principle, as philosophers like to suppose), whether that be in actual scientists' heads or in external, logically regimented representations. Does someone who knows or understands a theory like quantum field theory possess in her mind an enumerable list of all the (supposed) facts of the theory? Can all these facts even be written down or related? The credulous are invited to prove it; everyone else is welcome to continue reading.[18] We will make much more hay by moving on, relying on the intuition, winnable by long familiarity with scientific theories past and present, that theories are too multifarious and malleable, and often too rough, to be cut up and placed in the little fact-bundles that the fact-based picture demands.[19]

A more insightful way of seeing scientific theories is as akin to tools. Specifically, what I maintain is that theories (and models) are conceptual instruments used by scientists to produce descriptions and explanations of phenomena. Although to some this statement might suggest it, to adopt such a standpoint is not necessarily to take an instrumentalist or anti-realist line about the descriptions and explanations so produced.[20] The idea is rather meant to draw attention to the important role of the agent's abilities to use such conceptual tools, on the way towards fashioning a complete and accurate epistemological account of science.

Notably, Henk de Regt has made this basic idea central to his so-called "pragmatic" account of scientific understanding (de Regt, 2017; de Regt and Dieks, 2005). One might balk at his simultaneous characterization of the account as pragmatic and epistemic, since it is sometimes thought that pragmatic factors are those having to do with the desires and aims of subjects, in which case they would be subjective in a way that undermines any intended objectivity. Catherine Elgin suggests that many papers on understanding in the philosophy of science have indeed uncautiously flirted with this kind of subjectivity, which she insists would be a mistake, particularly since in the similar case of knowledge the fact that an agent is involved in the production of knowledge does not undermine the objectivity of her knowledge, nor does it make knowledge merely psychological.[21] De Regt's insistence on the essential role of the agent in an account of understanding is not, however, a concession of the subjectivity of understanding but the acknowledgment of an important cognitive component to understanding, one which involves the ability to produce knowledge, not just possess it.[22]

With these ideas related, I can now roughly distinguish two general kinds of epistemology and two accounts of progress based on them. According to the knowledge-centered epistemology, scientific theories are collections of propositions, so that knowing a theory is simply knowing a collection of propositions (or, for the empiricist, a distinguished subset thereof, i.e. the empirical facts). Epistemic progress according to the knowledge-centered epistemology is identified with the accumulation of knowledge (as in Bird's epistemic account) or the increasing verisimilitude of the epistemic content of scientific theories. According to the understanding-centered epistemology, scientific theories by contrast are to be viewed as conceptual tools, not as collections of facts. Understanding a theory is having the ability to use that theory to produce knowledge (of facts and explanations). Epistemic progress according to the understanding-centered epistemology is identified with the increase of understanding, that is, an increase in the ability to produce good descriptions and explanations of phenomena that pertain to the subject matter of the relevant theories.

I hold that the knowledge-centered epistemology gives a hollow picture of science. What especially proves it hollow is its inability to ground the growth of scientific knowledge. It is certainly able to account for the storage and sharing of knowledge, for propositional knowledge may be recorded and transmitted (assuming some basic abilities of comprehension and of judging the reliability of testifiers). But how can mere knowledge of propositions be the epistemic ground of an increase in knowledge? While one might fairly say that knowledge does beget more knowledge (for in a sense it does on the understanding-centered alternative), it does so not by the mere possession of it. Other, productive abilities, which are semantically more akin to understanding than knowledge, are essential.

Thus it is the understanding-centered epistemology that provides the conceptual framework needed for elucidating the epistemic progress of science. It is centered on the idea that growth is a matter of production, production which depends on having the right tools for the job and the ability to use them. Epistemically, then, what is distinctly valuable is cognitive ability, not its product. No particular fact or explanation produced is so valuable that its value exceeds the value of an understanding that subsumes it. This is because knowledge's epistemic value is dependent on the under-

[18] Pointing out that there are some "theories" which can be transparently represented as such a collection is not enough, for any such theory is far too impoverished, by themselves, to have any real scientific application. See, for example, the toy theories presented in (Halvorson, 2012).

[19] For further, related dissent from the fact-based picture, see (Churchland, 1990) and the discussion of "theory T syndrome" in (Wilson, 2006).

[20] The general point of view is widely adopted in the literature on scientific models. See, e.g., (Morgan and Morrison, 1999). Some use it to press for a more specific instrumentalist stance, e.g., (Cartwright et al., 1995).

[21] She raises this concern with respect to a collection of essays on scientific understanding (de Regt et al., 2009), which she reviews in the Notre Dame Philosophical Reviews: https://ndpr.nd.edu/news/scientific-understanding-philosophical-perspectives/.

[22] Cf. (Friedman, 1974, 7–8).

standing to which it is related.[23] Although I freely grant that having an understanding does depend on the possession of some knowledge, this knowledge is not fundamentally constitutive of the associated degree of understanding. It follows that the value of understanding is not to be derived from the value of the knowledge associated to it. The growth of knowledge is instead to be seen as an essential concomitant of the growth of understanding. The primary epistemic aim of science is therefore best characterized as understanding rather than knowledge; progress should accordingly be characterized, then, as increase in understanding.

3. PROBLEM SOLVING AS A MEASURE OF SCIENTIFIC PROGRESS

As an illustration of how the understanding-centered epistemology fits naturally with the problem-solving approach to scientific progress, I will make use of Kuhn's familiar division of science recurring stages, and show how they may be interpreted in light of this epistemology. I choose Kuhn's account not because I believe it gives the best characterization of how science proceeds but because it is simple, well-known, and intuitively illustrates the connection between problem-solving and understanding.

Recall that for Kuhn science is roughly split into two periodic phases: normal science and revolutionary science. Normal science is carried out by practitioners working within a paradigm, which, besides the scientific theories relevant to the phenomena studied under that paradigm, includes exemplars, shared values, a material culture of instrumentation, and metaphysical views. Whatever else these elements contribute to a paradigm's role in science, during normal science they are meant to legitimate "the puzzles and problems that the community works on" (Kuhn, 1996, xxiii). The paradigm sets out, broadly, which problems practitioners should aim to solve and which methods and techniques should be used to solve them. Of course according to Kuhn's picture we should expect that anomalies appear. Anomalies threaten the paradigm, until eventually they push scientists to seek a replacement paradigm, ushering in the phase of revolutionary science. Once a new paradigm is adopted, the cycle then begins anew.

What is the epistemic aim of puzzle-solving during normal science? In light of the understanding-centered epistemology, I suggest that one important function of solving puzzles and problems is evaluative: it is done to determine how effective the paradigm is at solving the problems it sets. Of course, an individual puzzle-solver need not care about assessing the viability, explanatory power, etc. of his paradigm. Even so, solving puzzles has this function for the community of scientists. The assessment of the paradigm through puzzle-solving is not direct per se, since whether a scientist solves a puzzle depends not only on whether it can be solved given the resources of the paradigm but also on whether the scientist himself possesses the necessary skill to solve the puzzles he attempts. If he succeeds at solving many and various puzzles, then we may say that he proves the paradigm (indirectly), but he also directly "proves himself an expert puzzle-solver" (Kuhn, 1996, 36). In other words, he demonstrates the understanding possible with the epistemic resources of the paradigm, and he demonstrates his own understanding achieved under this paradigm as well.

Normal science is highly cumulative according to Kuhn. According to the understanding-centered epistemology, this is because a skilled practitioner, one who has an expert understanding, is able to produce facts and explanations cumulatively through the use of an essentially stable conceptual framework. According to Kuhn, such a practitioner contributes knowledge in three ways: (1) by extending the knowledge of the facts that established the paradigm; (2) by increasing the extent of match between predictions and those facts; (3) by further articulating the paradigm itself. The salience of normal science and its highly cumulative creation of knowledge might therefore make a knowledge-centered epistemology inviting, but this would be to overlook much of the epistemology required to make sense of this very cumulative increase in knowledge.

The second phase, revolutionary science, comes about after persistent anomalies eventually overcome the resistance to change of scientists bound within a paradigm, which leads to a breakdown of the normal science puzzle-solving activity of scientists. As anomalies accumulate, Kuhn describes science as being "in a state of growing crisis" (Kuhn, 1996, 67). Scientists do not respond to crisis by abandoning their paradigm right away, although they do begin considering alternatives which might solve the old paradigm's mounting problems. Thus, problem-solving is a crucial part of revolutionary science, as it is in normal science. If a newly developing paradigm's supporters are competent (and fortunate), "they will improve it, explore its possibilities, and show what it would be like to belong to the community guided by it" (Kuhn, 1996, 159). I suggest that there is a clear epistemic reason to these activities too, namely, to develop an understanding which is lacking in the present paradigm.

[23] Pritchard (2010) defends the final value of explanatory understanding on the grounds that it is an achievement. I do not defend a particular account of final value in this paper, although it seems that adapting Pritchard's view to theoretical understanding is one possibility.

Of course in Kuhn's view there are no rules to assess whether one such "understanding" is better than another, since it is crucial to his view that there is no rationally compelling reason that practitioners adopt a particular paradigm: "individual scientists embrace a new paradigm for all sorts of reasons and usually for several at once" (Kuhn, 1996, 152).[24] Nevertheless, Kuhn does say that scientists must be convinced on two important points: (1) that the new paradigm must promise to resolve some outstanding problem which can seemingly be solved in no other way; (2) that the new paradigm must also preserve a large part of the prior paradigm's problem-solving ability. Both of these pertain to the "problem-solving effectiveness" (Laudan's term) of the paradigm and are readily assimilated into the understanding-centered epistemology.

Problem-solving therefore gives scientists two measures of understanding, a backward-looking one and a forward-looking one, so to speak. In normal science problem-solving is backward-looking and evaluative. It is primarily intended to assess the understanding so far achieved in the paradigm. The production of cumulative knowledge in the form of new facts and explanations is secondary. In revolutionary science problem-solving is forward-looking and diagnostic. It is primarily intended to assess the potential for understanding which may be achieved through solving problems with the new resources furnished by the developing paradigm. The production of individual items of knowledge is, again, secondary. Thus Kuhn's problem-solving account gives an intuitive demonstration of the understanding-centered epistemology and how it applies to the problem-solving approach to scientific progress.

4. UNDERSTANDING, EXPLANATION, AND KNOWLEDGE

Above I contrasted two broad epistemological approaches to characterizing the progress in science: the knowledge-centered and the understanding-centered. I argued in favor of the latter and showed how the problem-solving approach fits it naturally. As I noted, one might demur from the beginning, however, objecting that this story rests on an illusion, that is, that there is actually no substantive epistemological distinction between knowledge and understanding. If so, then the growth of understanding could be accounted for in the traditional, knowledge-based epistemological terms.[25] I will not attempt a full defense of the distinction on which my argument rests, for it surely demands a separate treatment, but I will offer some reasons not to assimilate understanding to knowledge too quickly.[26]

Recall that I argued that scientific progress should be characterized in terms of theoretical progress, since the epistemic content and value of science resides in its theories and models. Of course, it is consistent with this specific claim that scientific theories have epistemic value because of the propositional knowledge which constitutes them. This is a core idea of the knowledge-centered account of scientific progress; improving our theories means increasing our knowledge. It is also consistent with my preferred view, that scientific theories have epistemic value because with them one is able to understand, that is, has the ability to produce explanations and descriptions of phenomena. This is the core idea of the understanding-centered account of scientific progress; improving our theories means increasing our understanding.

When put so, the two approaches are not obviously dichotomous. It is conceivable that the cognitive abilities which distinguish understanding may be rendered in terms of propositional knowledge or that propositional knowledge be rendered in terms of cognitive abilities. Nevertheless, I believe it is ill-advised to attempt to reduce one concept to the other, for each plays an important and distinctive role in epistemology.

Theoretical understanding, as I have said, is a particular kind of objectual understanding. It is in virtue of understanding a relevant theory that one is able to produce an explanation or description of a phenomenon, and that is true whether that explanation or description is already in one's grasp (in other words, known), or it must be produced through some exercise of reasoning. Let us focus on explanation.

When one is able to deliver an explanation on the basis of having relevant theoretical understanding, then we may say that one has explanatory understanding. Moreover, we may say that one has propositional understanding too, namely of the propositions involved in that particular explanation.[27] Thus, in an intuitive sense, understanding "flows down" from theory to proposition: objectual understanding delivers explanatory understanding, and both deliver propositional understanding of certain propositions.

[24] See also Kuhn's discussion of values in (Kuhn, 1977).

[25] Kvanvig in particular has drawn attention to this concern, and the issue is one of the central debates in the epistemology of understanding (Kvanvig, 2003, 2009).

[26] Some also claim that understanding is just another kind of knowledge, namely "know-how" rather than "know-that." Advocates of this view include Zagzebski (2001) and Hills (2016). At the very least this kind of cognitive know-how is not so analogous to conventional examples of know-how, like riding a bike, as (Sullivan, 2018) argues.

[27] Strevens (2013) describes these three kinds of understanding "understanding with," "understanding how," and "understanding that."

Knowledge, by contrast, "flows up" from proposition to theory. This is because we take knowledge of propositions as the basic form of knowledge. Knowing an explanation of a phenomenon implies knowing certain propositions involved in that explanation, and knowing a theory implies knowing certain explanations and descriptions that are important concomitant of that theory.

The conceit of the knowledge-centered epistemology is that the latter scheme is entirely sufficient to account for the epistemic value of our theories, explanations, and propositions. The aggrandizement of propositional knowledge casts a strong glare, in such a way that important facets of epistemology like learning, conceptual change, and inference come to be seen as relative trivialities, items to be baked into the propositional mold. But they are hardly trivialities, and they are not so easily handled by the knowledge-centered epistemology.

I press only one well-known case here: no amount of knowledge can stand in for the ability to infer. The point is most familiar from Carroll's famous story of the tortoise and Achilles (Carroll, 1895).[28] The tortoise in the tale is willing to assent to as many premisses as Achilles wishes to provide him: that P, that $P \rightarrow Q$, that $\{P, P \rightarrow Q\} \vdash Q$, etc. However, the tortoise will not assent that Q, that is, will not infer that Q, despite what seems to be a logical compulsion! Propositional knowledge by itself cannot capture inference.[29]

Understanding, as I have characterized it, is intended to have this function.The ability to furnish explanations and descriptions, which I have associated with understanding, is fundamentally the ability to make inferences: deductive inferences, inductive inferences, abductive inferences, etc. The epistemic value of understanding is therefore substantially built on the epistemic value of inference. While the familiarity of inference may easily belie its epistemic value, without the ability to infer we could hardly hope be in the possession of any knowledge whatever.

Other philosophers have argued that understanding is distinct from knowledge on different grounds. They generally maintain the propositional nature of bodies of information and appeal variously to a certain holism, coherence, integration, or unification inherent in those bodies of information as the mark of understanding (Friedman, 1974; Cooper, 1994; Zagzebski, 2001; Kvanvig, 2003; Elgin, 2007; Gardiner, 2012). These suggestions have remained too vague to account for the epistemic value of understanding. Specifically, I do not see how they can ground the abilities that I have claimed are central to theoretical understanding.

Of course, theories are in some sense holistic, coherent, integrated, and unified. Yet it seems to me that these features have mainly to do with distinguishing theories from one another, that is, with epistemic compartimentalization, rather than with distinguishing understanding from knowledge. This compartimentalization is certainly important. Indeed, I am inclined to hold that what is constitutive of a theoretical understanding is the grasp of a compartimentalized collection of (non-propositional) concepts. A body of propositions may be an essential adjunct to any such set, but it is not responsible for the abilities which I use to describe understanding. I emphasize conceptual grasp instead of propositional grasp, for it is concepts that are our principal tools of inference and learning, not a full proposition. That is to say, a grasp of a collection of relevant concepts is what grants us the ability to produce knowledge and explanations pertaining to some phenomenon. Thus it is conceptual competency that is ultimately behind a theoretical understanding, and this provides a principled basis for distinguishing understanding and knowledge.

Although it is not my aim to defend this view in full here, it is worth concluding with a few significant consequences which follow from this conceptual characterization of understanding. First, there is evidently no sharp distinction between semantic understanding and cognitive understanding.[30] Second, understanding is evidently not strictly factive, for concepts are not true or false. That said, understanding is nevertheless "tethered to the facts," as Elgin says (albeit in a different sense than the way she means it). Our conceptual understanding of the world is an "understanding of the-world-as-modulated-through-a-particular-theory" (Elgin, forthcoming , 4). So, of course our theories answer to the world—we see it in the progress of science: the progress of our understanding.

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[28] The story is related to understanding by Stroud (1979) and discussed in relation to the present issue by Gardiner (2012).

[29] Khalifa claims that the possession of information concerning inferential connections is all that is required to complete an explanatory story, much like Achilles in the story. Although he states that he is willing to concede that the ability to infer may not be reducible to knowledge, he dismisses the role of inference in explanatory understanding as "so thin as to trivialize understanding" (Khalifa, 2012, 28).

[30] This claim is also made by Cooper (1995).

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