Understanding the Progress of Science

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Abstract

A problem-solving-based account of scientific progress that takes understanding as the principal epistemic aim of science is developed and defended against knowledge reductionism.

1 Introduction

Much of the recent explosion of literature on scientific progress was ignited by Bird's provocative article "What Is Scientific Progress?" (Bird, 2007), where he advocates an "epistemic" account of scientific progress, a kind of view which he alleges is lately overlooked, despite its venerable history. In making room for his account, Bird criticizes what he takes to have been the most prominent accounts of scientific progress advanced in the latter half of the 20th century. He claims that realist philosophers of science have often taken truth to be the ultimate goal of science and its progress to be properly characterized by an accumulation of truths, or at least an approximating approach to them. By contrast, historically-minded philosophers of science and anti-realists have frequently rejected the realists' notion of truth as a goal of science, instead preferring to characterize progress in terms of, among other things, success in problem-solving, as in the well-known views of Kuhn (1996) and Laudan (1977). In his paper, Bird criticizes the realists for overlooking the importance of justification to progress and the anti-realists for giving up on truth—both regarded as being essential elements of the generally received conception of knowledge in analytic epistemology. According to Bird, it is knowledge that should properly be regarded as the principal aim of science: science makes progress precisely when it realizes the accumulation of scientific knowledge.[1]

The ensuing discussion has generated many responses to Bird's view (Dellsén, 2018), many of which have come from supporters of (some version of) the truth-based realist account, but

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[1]Bird calls his account "epistemic," in line with the usual assumption that epistemology is fundamentally concerned with knowledge (Bird, 2010). This is a point which will be under dispute in this paper, since I (and many contemporary epistemologists) hold that the subject matter of epistemology has a broader scope than just knowledge, particularly the mainstream conception of it in analytic epistemology.

there have also been some supporters of Bird's view that knowledge is the aim of science, as well as others that have promoted accounts based on the idea that understanding makes better sense as a goal of science than knowledge. For the most part, the authors involved in this debate are avowed scientific realists, so they typically dismiss anti-realism quickly, and along with it the problem-solving approach to scientific progress, which they take to be untenable (or irrelevant) due to its assumed commitment to anti-realism. In my view, this attitude towards the problem-solving approach to scientific progress is unfortunate, not only because I have found it insightful for understanding important episodes in science in my own work (McCoy, 2015, 2019) but, more generally, because much of what is of value in the problem-solving approach is in fact independent of the essentially metaphysical issue of scientific realism, based as it is on the importance of scientific problems and problem-solving within scientific practice (Nickles, 1981).

Nevertheless, whatever the merits of the problem-solving approach, it is fair to say, as Bird does, that it lacks a clearly identified epistemic (or, as Dellsén prefers to say, cognitive) goal. Indeed, Kuhn and Laudan explicitly reject characterizing it in familiar epistemological terms, for they famously reject the presuppositions of mainstream epistemology, especially those concerning the nature of knowledge, truth, and justification.[2] As for the prospects of developing an alternative approach to epistemology, one which takes its cue from the problem-solving practices of science, one will find relatively little encouragement in the principal works of Kuhn and Laudan, instead only scattered remarks such as that problem-solving is "the single most general cognitive aim of science" (Laudan, 1977, 124) (which leaves it completely unclear why problem-solving in itself should be a valuable aim at all) or that scientists solve puzzles because they simply like the challenge (Kuhn, 1996, xx).[3]

The course of epistemology has, however, broadened in the intervening years (i.e., since the heyday of debates over scientific progress), such that it now seems possible to assimilate the problem-solving approach to scientific progress and its distinctive characteristics into the currents of epistemological inquiry. My aim in this paper is to furnish a problem-solving-based characterization of the progress of science that addresses the shortcoming identified by Bird, and I do this by taking understanding rather than knowledge as the principal epistemic aim of science. While it is intuitive that the point of solving problems is to achieve a higher degree of understanding (and not just to come to know their solutions), this intuitive idea is able to receive a deeper philosophical explication thanks to relatively 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 (Elgin, 1996; Zagzebski, 1996; Kvanvig, 2003; Riggs, 2003; Pritchard, 2010) making compelling cases that it is in fact understanding which has the needed kind of distinctive value to make sense of our epistemic practices. 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 the proper characterization of progress in science and, in particular, fit well with the problem-solving approach.

[2]As Laudan says, "the initially plausible, and broadly held, view that theory testing and theory evaluation are at root...epistemological activities" is "fundamentally mistaken and systematically misleading" (Laudan, 2000, 165). Kuhn, for his part, 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, a "goal set by nature in advance" of our inquiry into it (Kuhn, 1996, 171).

[3]That said, Laudan does promote a sort of meta-epistemology of his own, which he calls "normative naturalism" (Laudan, 1984, 1987). According to normative naturalism, the aims of science shift over time in a way that requires re-conceiving the remit of "epistemology" as scientific values change.

As noted above, some responses to Bird's arguments have already made the move to base their accounts of scientific progress on understanding rather than knowledge (e.g., (Dellsén, 2016; Bangu, 2017)). Despite basic agreement on the significance of understanding to science, advocates of these views have embraced diverse analyses of the concept of understanding. To my mind, though, none of these analyses is fully adequate to grounding a satisfying problem-solving-based account of progress, for none captures the essentials of problem-solving, which I regard as integral to the practice of science. Therefore, my approach in this paper will be to consider the role and significance of problem-solving in science from the very beginning, in order to bring out its intuitive relation to our pre-theoretic concept of understanding (§2). This relation will then feature centrally in my own account of what (scientific) understanding is and why I believe it is the principal epistemic aim of science (§3). In the final section, I defend the account against the threat of its reduction to (scientific) knowledge (§4).

2 Problem-Solving as a Measure of Scientific Understanding

Rather than survey actual cases of problem-solving in science or refer to scientific work on problem-solving, I will make use of Kuhn's well-known analysis of scientific change into recurring stages of normal and revolutionary science in order to draw the role and significance of problem-solving in science. I do this not because I believe Kuhn gives the best characterization of how science proceeds but simply because his views are widely known and therefore can be easily used to highlight some key aspects of problem-solving practices in science. I will make an intuitive connection between these practices, as seen in Kuhn's stages, and our ordinary, pre-theoretic conception of 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 such things as exemplars, shared values, a material culture of instrumentation, and also 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 speaking, which problems practitioners should aim to solve and which methods and techniques should be used to solve them. According to Kuhn's picture, we should nevertheless expect that anomalies inevitably appear. These anomalies eventually come to threaten the paradigm, at last pushing scientists to seek a replacement paradigm, which then ushers in the phase of revolutionary science. Once a new paradigm is adopted, the cycle then begins anew.

Going beyond Kuhn's particular descriptive aims, we may ask, "what is the primary epistemic aim of puzzle-solving during normal science?" To a philosopher tutored in mainstream epistemology (the "theory of knowledge"), the natural answer would be "knowledge of puzzle-solutions." And indeed, normal science has a highly cumulative character characteristic of ordinary knowledge acquisition. Kuhn himself mentions three ways that scientific practitioners operating within normal science contribute to the accumulation of knowledge (Kuhn, 1996, 24): (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. It is therefore inviting, given the salience of normal science in the overall course of science (according to Kuhn anyway) and this highly cumulative creation of knowledge, to regard knowledge as the principal epistemic aim of normal science's puzzle-solving.

Certainly, extended and increased knowledge of facts, explanations, articulations, etc. are of significant epistemic value. However, no pure axiology of knowledge can explain why scientists seek *certain* facts, *certain* explanations, *certain* articulations, etc. in the context of normal science (a point which Bird, incidentally, makes himself). Items of knowledge are all alike in being items of knowledge; to distinguish some items of knowledge as more valuable than others therefore demands that additional considerations be brought to bear. For some philosophers, these additional considerations are pragmatic, psychological, sociological, etc.—not properly epistemic. Is there another, better way to connect puzzle-solving and epistemology, one that does not leave much of the practice outside the latter's scope?

Indeed there is, for there is another important function of solving puzzles and problems set by a paradigm, one that is primarily *evaluative* in character, which is to determine how effective the paradigm is at solving the problems it sets. For sure, an individual puzzle-solver need not personally care about assessing his or her paradigm's viability, explanatory power, or whatever else is regarded as of epistemic value. Even so, on analysis solving puzzles can be seen to have this evaluative function for both the individual scientist and the community of scientists alike, since whether a scientist solves a puzzle intuitively depends not only on whether it can be solved given the resources of the paradigm by the community of scientists but also on whether the scientist him- or herself possesses the necessary skill and knowledge to solve the puzzles he or she attempts. If he or she succeeds at solving many and various puzzles, then, as Kuhn says, he or she "proves him[- or her]self an expert puzzle-solver" Kuhn (1996, 36). While such expertise at puzzle-solving may certainly have its social merits, from an epistemological point of view, individual or collective success at solving puzzles is also naturally read as *evidence* (defeasible evidence, of course) of the paradigm's effectiveness at solving the problems it sets.

To the typical realist philosopher of science, scientists' puzzle-solving practices would be understood as intended to produce evidence in order to assess the degree to which the paradigm (theory, model, etc.) is true or truthlike (or known or knowledge-like). However, even if occasionally scientists *think* that is what they are doing, they are (almost universally) in no position to actually make such an assessment (due, e.g., to the problem of unconceived alternatives, etc.). Scientific realism may be a live philosophical issue, but it is not one that can (or should) make a difference to what scientists actually do. Therefore, it remains to find if there is a way to read the practical aim of puzzle-solving practices in an epistemological way while still maintaining a clear connection to scientific practice.

I propose that there is such a way, one rooted in our intuitive, pre-theoretic concept of understanding: scientists are (whether individually or collectively) evaluating their degree of *understanding*, not knowledge. In the first place, it makes intuitive sense to say that a successful puzzle-solving scientist in normal science is both demonstrating the understanding afforded by the epistemic resources of the paradigm and also demonstrating his or her own understanding achieved through this paradigm as well. Scientists, of course, may be seen as demonstrating their knowledge and the knowledge inherent in their paradigm as well. Attention to the practice of puzzle-solving, however, suggests that this kind of "understanding" sought by puzzle-solving has a somewhat different character than knowledge. It emerges in particular from thinking about what makes a normal science practitioner skilled, what someone who has an expert understanding (of his or her paradigm) can do. Intuitively, a skilled scientific practitioner (in normal science) is someone who is *able* to *produce* facts and explanations, specifically ones that solve empirical and conceptual problems set by his or her paradigm—in particular by using the conceptual means at his or her disposal (i.e., as given the paradigm). Thus, puzzle-solving (1) is a test of ability (not of knowledge, at least not directly), which (2) does not generally involve the prior possession (knowledge) of puzzle-solutions (indeed, if the puzzle-solver had the solution already, then we could hardly regard his or her activity as puzzle-solving, much less him or her as a skilled puzzle-solver). Understanding, unlike knowledge, aptly describes the aim of puzzle-solving given these two conditions on it, for it is intuitively correct to say that puzzle-solving tests one's ability to understand (and not to know), and it is clear that one can understand how to solve puzzles without knowing their solutions in advance.

Further aspects of a problem-solving-oriented conception of scientific understanding are suggested by the second phase of Kuhn's scheme, revolutionary science. Let us briefly recall how Kuhn describes revolutionary science. The phase first emerges after persistent anomalies eventually overcome the resistance to change of scientists bound within a paradigm, which leads to the 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 prevailing paradigm's mounting problems. However, if a newly developing paradigm's supporters are competent (and fortunate), then, as Kuhn says, "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).

From this brief description of revolutionary science, it is evident that problem-solving is also an essential activity of this phase, although here it takes on a slightly different character than it does in normal science (i.e., it is not mere "puzzle-solving" anymore, for the puzzles are no longer set in advance by the dominant paradigm). An expert revolutionary science problem-solver may not be an expert normal science puzzle-solver, and vice-versa, but both are distinguished by their ability to produce solutions to contextually salient problems. Thus, the epistemic rationale behind "revolutionary" activities is intuitively characterizable in terms of understanding as well, to wit, to develop a novel understanding which is lacking in the present paradigm. Of course, for Kuhn himself there are no rules to assess whether one such "understanding" is objectively better than another, since it is crucial to his view that there is no rationally compelling (i.e., rule-based) reason that practitioners adopt a particular paradigm (Kuhn, 1977). Nevertheless, Kuhn does allow that scientists must be convinced on two important points: (i) that the new paradigm must promise to resolve some outstanding problem which can seemingly be solved in no other way; (ii) 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" (borrowing Laudan's term) of the new paradigm in comparison to the old. It is appealing, therefore, to interpret problem-solving in revolutionary science in similar epistemological terms, namely, as evaluative of the potential understanding afforded by a newly developing paradigm.

By examining both normal science and revolutionary science, we see that the problem-solving activities found in Kuhn's account of science suggestively point to a single, unified epistemic goal of understanding rather than knowledge. There are, however, important differences between the problem-solving of the two phases. Normal science problem-solving activity is "backward-looking" and assessive, for it is primarily intended to evaluate the degree of understanding *so far achieved* in the current, established paradigm. Importantly, the production of cumulative knowledge in the form of new problem-solutions (facts and explanations) is secondary and instrumental to this more essential function. In revolutionary science, by contrast, problem-solving is "forward-looking" and diagnostic, for it is primarily intended to evaluate the potential for understanding which *may be achieved* through solving problems with the new resources furnished by the future paradigm under development. The production of individual items of knowledge is, again, secondary and instrumental to the more essential function of establishing a new understanding.

3 Understanding as the Principal Epistemic Aim of Science

The previous section suggested an intuitive connection between problem-solving and a form of understanding, established by reference to the problem-solving activities of science. In this section, I will now proceed more systematically in the task of developing an account of scientific progress, one which is based on the concept of understanding which is suggested by the problem-solving practice of science. I also aim to show that understanding, not knowledge, is the principal epistemic aim of science and is the epistemic concept against which scientific progress should be primarily measured.

Observers of both the older and newer debates about scientific explanation and understanding will no doubt be aware that I am far from alone in suggesting the relevance of understanding to the issue of scientific progress. Philosophers of science have frequently mooted the idea that understanding is an important product of science, especially in motivating their own favored accounts of scientific explanation (e.g., (Friedman, 1974; Strevens, 2008)). However, this was often done in the past without explicating precisely how explanation is related to understanding—or even explaining what understanding is (as Kim (1994) and de Regt and Dieks (2005), for example, have remarked). Persistent uncertainty over the nature of understanding has made room for another long-standing tradition in the philosophy of science according to which understanding is is merely "psychological" and hence lacking in any objective epistemic significance at all, starting with Hempel's influential studies of explanation (Hempel, 1965), continuing through van Fraassen's pragmatic account of explanation (van Fraassen, 1980), and finding more recent expression in the work of Trout (2002).

The recent tide of support in epistemology for a genuinely objective, epistemic notion of understanding (e.g., (Elgin, 1996; Zagzebski, 1996; Kvanvig, 2003; Riggs, 2003; Pritchard, 2010)), which is one of the main motivations for this paper, is not without its critics. Against this tide 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. Indeed, several philosophers have argued that understanding reduces to (or merely is a species of) knowledge, especially explanatory knowledge (e.g., (Grimm, 2006; Khalifa, 2012; Strevens, 2013)). If it were true that understanding really is essentially knowledge (at least for all epistemological purposes), then the import of understanding would be quite minimal indeed. I defer my discussion of this important issue to the final section of this paper in favor of first arguing for the priority of understanding as the epistemic aim of science, relying for now on the intuition (and the indications of the previous section) that knowledge and understanding are sufficiently distinct concepts.

So much for preparatory remarks. To begin elaborating my account of scientific understanding, I wish to draw attention first to the epistemic significance of (theoretical) explanations in science, which indicates that the distinctive locus of epistemic value in science is not the bare scientific fact—it is scientific theory. By theory I mean not only theory in the sense of general, abstract laws, etc. but also other explanatory and descriptive resources, from scientific frameworks or paradigms to concrete models. Empiricist scruples may incline some towards the view that theory is too ephemeral to have real epistemic significance, which leads to the position that the sole epistemic content of science should not to be identified with scientific theory but with the empirical facts. Nevertheless, even the most hard-nosed empiricist must admit that scientific theory is indispensable for securing the greater part of those empirical facts which we do possess. Thus, in the case where scientific explanations are accepted as genuinely epistemic in character, theory is clearly the fundamental seat of epistemic value in science; when not, theory remains the indispensable vehicle of epistemic value in science, and that will suffice for present purposes.

Since one can, linguistically at any rate, treat scientific theories as objects in epistemic locutions attributing understanding to an agent, one might, following Kvanvig, characterize our understanding of scientific theories as "objectual" (Kvanvig, 2003). Although many philosophers have been willing to entertain a category of objectual understanding, it remains in dispute how this kind of understanding should be properly analyzed. For example, 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 among kinds of understanding and that understanding a theory can be described as a kind of objectual understanding, I will not be following those who hold that theories are best thought of as bodies of propositions that collectively admit of belief (for reasons to be explained shortly and also further in the final section). I will also avoid making use of the notion of objectual understanding directly, since for the purposes of scientific epistemology the category of objectual understanding is far too broad. Phenomena can be understood "objectually" just as well as theory, yet theories and phenomena must be distinguished into epistemologically distinct categories in order to make sense of scientific methodology, particularly as it is theories that explain phenomena and not vice versa. Our understanding of phenomena is asymmetrically dependent on understanding theory. Instead I will prefer to speak of *theoretical understanding* (Saatsi, 2019) and understanding phenomena *with* theories (Strevens, 2013).

One might think that there is nevertheless not much of epistemological significance in marking a distinction between scientific facts (or propositions, if you like) and scientific theories, since it might seem that theories are nothing more than collections of scientific facts (or propositions). To be sure, if scientific theories were merely collections of propositions, then "believing a theory" would be nothing more than believing that collection of propositions. I allow, at least for some logical and epistemological purposes, that treating theories as if they were such is sometimes fruitful and relatively harmless. Actual theories in scientific practice, however, the ones that scientists use, are surely not collections of facts, propositions, or whatever else. In the first place, scientific theories are clearly not learned as collections of facts and are not communicated as such either (which is not to say that learning and communicating facts are not, respectively, part of learning and communication). If someone memorized the entirety of Weinberg's *Quantum Theory of Fields* (in three volumes), they would hardly thereby come to know quantum field theory, let alone understand it. That is because understanding (or knowing) a theory is a matter of practical engagement with that theory, applying it to problems set by the descriptive and explanatory scope of the theory. Therefore, it is essential to distinguish scientific facts from scientific theories in order to understand the practice of science.

Therefore, I claim that theoretical understanding is essentially *practical* and *constructive*. To practicing scientists, scientific theories (or models) are *tools* to be applied, specifically in order to understand (including explaining and describing) phenomena. Much as the nature of a hammer is not its mere being as an object but primarily as a piece of equipment, a means of hammering, the nature of theories is not their mere being as objects (bodies of knowledge) but primarily as a means of theorizing about phenomena. They are the tools of science. Although to some this perspective on theories might suggest an unpalatable "instrumentalism," highlighting the practical dimension of theories does not actually entail anything untoward about their factual status, much less about the descriptions and explanations produced by their application.[4]

[4]Such a generally practical and constructive point of view is widely adopted already in the literature on scientific models. Some do use it to press for a more specifically anti-realist stance towards theories, e.g., (Cartwright et al., 1995), but not all—cf. the different perspectives on offer in (Morgan and Morrison, 1999).

Instead, the practical and constructive nature of understanding should draw attention rather to the central role of the agent's abilities to use such conceptual tools to solve problems. In the literature on scientific understanding, de Regt in particular has emphasized agent abilities in this way, making them central to his "pragmatic" account of scientific understanding (de Regt and Dieks, 2005; de Regt, 2009, 2017). De Regt's (and my) insistence on the essential role of the agent in an account of understanding is not a concession of the subjectivity of understanding but rather the recognition of an important cognitive component to understanding, one which involves the ability to *produce* knowledge, not just possess it.

The basic statement of my account of understanding and progress with respect to it can now be given. First, possessing a (scientific) understanding of some subject matter is mediated by one or more (scientific) theories of that subject matter—this is the requirement of "understanding phenomena with theories." Second, understanding some subject matter with a theory depends on having the ability to produce explanations and descriptions pertaining to that subject matter, that is, solving explanatory and descriptive problems within the scope of that theory. Hence, understanding a theory means being able to understand phenomena with that theory. Third, and finally, progress in understanding simply involves improvement in theoretical understanding, which is a matter of improved ability to explain and describe phenomena, the degree of which is something evaluable by a problem-solving standard.[5]

To argue for the priority of this kind of understanding among epistemic aims of science, I will first introduce two broad, archetypal conceptions of epistemology and accounts of theoretical progress based on them. According to what I will call the *knowledge-centered epistemology*, scientific theories are collections of propositions, so that knowing a theory is simply knowing a collection of propositions. 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 garden-variety realist). According to what I will call the *understanding-centered epistemology*, by contrast, scientific theories are conceptual tools, not collections of facts. Understanding a theory is having the ability to use that theory to produce knowledge (of facts and explanations), especially in response to scientific problems. Epistemic progress according to the understanding-centered epistemology is identified with the increase of understanding, an increase in the ability to solve scientific problems by producing good descriptions and explanations of phenomena that pertain to the subject matters of the relevant theories.

The understanding-centered epistemology acknowledges the epistemic significance of *productive* abilities in the epistemology of science. The knowledge-centered epistemology focuses only on the value and significance of certain *products* of science: items of knowledge. From the perspective of the understanding-centered epistemology, however, these items of knowledge have only instrumental value and significance, insofar as they contribute to increased understanding. Leaving no place for the productive abilities necessary for explaining and grounding the growth of knowledge, the knowledge-centered epistemology can only give a static, skeletal picture of science and its epistemology. Certainly, such an epistemology is able to account for the storage and sharing of items of knowledge, as propositional knowledge may be recorded and transmitted (assuming some basic abilities of comprehension and of judging the reliability

[5] As Insa Lawler has pointed out to me, Strevens (2013, 515) states a similar sounding account of understanding: " to understand a theory is to have the ability to use the theory to construct, or at least to comprehend, internally correct scientific explanations of a range of phenomena." Where my view departs most significantly from Strevens' is that he links understanding to the grasping of explanations, the latter construed as a structured set of propositions, whereas I believe understanding involves the ability to provide explanations and descriptions which respond to problems set by the theoretical context.

of testifiers). It can also give a simple standard of progress, since static bodies of propositional knowledge can be compared both synchronically and diachronically. But how can such items of knowledge alone license increases in knowledge? Epistemologists of science have traditionally avoided this crucial issue by shunting the means of increasing knowledge off into "psychology" or "pragmatics" (as in empiricist or hypothetico-deductivist approaches). However, I object strongly to this maneuver, for to do so is to limit the scope of epistemology and limit our philosophical understanding of science. There must be a place made for the scientist, and not just the "science."

It is only 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 speaking, what is intrinsically valuable is cognitive ability, not its product alone. This is because knowledge's epistemic value is dependent on the understanding to which it is related. To be sure, having an understanding does depend on the possession of some knowledge, but this knowledge is only partly constitutive of the understanding possessed. And while the growth of knowledge is an essential concomitant of the growth of understanding, it is the growth of understanding that is the principal epistemic goal of scientific practice. Scientific progress should accordingly be characterized, then, as increase in understanding.

4 Understanding, Explanation, and Knowledge

Just above I contrasted two broad epistemological approaches to characterizing progress in science: the knowledge-centered and the understanding-centered, arguing in favor of the priority of the latter, especially for how it captures the dynamic growth of science. The existence of this contrast, however, depends on my conception of understanding not being reducible to knowledge (or some arrangement of knowledge).[6] If it is, then my account rests on an illusion, for then the growth of understanding can be accounted for in traditional, knowledge-based epistemological terms, despite my claims to the contrary. While I cannot give an elaborate defense of the distinction on which my argument rests in the remaining space available here, I can at least offer some further reasons why assimilating understanding to knowledge is a mistake.[7]

In the previous section, I argued that scientific progress should be characterized in terms of theoretical progress, since the epistemic content and value of science resides predominantly in its theories. Of course, it is consistent with this claim that scientific theories have epistemic value because of the propositional knowledge which constitutes them (or because they approximate propositional knowledge). This is a fundamental idea of what I have called the

[6]It is worth mentioning that some relate understanding not to propositional knowledge ("know that") but to a different kind of knowledge, some kind of practical knowledge or "know-how," such as Zagzebski (2001) and Hills (2016). While relating understanding to knowledge in this way has a strong affinity with the account I offer here, I hesitate to make too much of the connection, because the practical, "cognitive know-how" of understanding is not obviously analogous to conventional examples of know-how (like riding a bike or wielding a hammer) (Sullivan, 2018).

[7]Other philosophers have argued that understanding is distinct from knowledge on different grounds. However, they generally maintain the propositional nature of theories (regarding them as 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; **?**). Although I cannot argue it here, I believe that these suggestions cannot account for the epistemic value of understanding as understood in this paper. Instead, it seems to me that these features have mainly to do with distinguishing theories from one another, i.e., with epistemic compartmentalization.

knowledge-centered account of scientific progress: improving our theories means improving our knowledge (whether that be restricted to empiricist-sanctioned knowledge or else approximate knowledge with respect to the world-as-everything-that-is-the-case). It is also consistent, though, with my preferred view, that scientific theories have epistemic value because with them one is able to understand. This is the core idea of what I have called the understanding-centered account of scientific progress: improving our theories means increasing our understanding. At this level of description, then, the two approaches are not obviously opposed, for it is conceivable that the cognitive abilities which are distinctive of understanding may be rendered in terms of propositional knowledge or that propositional knowledge may be rendered in terms of cognitive abilities.

However, the reduction of one concept to the other is ill-advised, for each plays an important and distinctive role in a comprehensive scientific epistemology. To see how, consider the activity of solving explanatory problems. When one is able to deliver an explanation, prompted by an explanatory problem, it is intuitive to say that it is because one has the relevant *theoretical understanding* (understanding "with," as Strevens (2013) puts it). Owing to one's theoretical understanding, one has additionally an *explanatory understanding* of the explanandum (understanding "why") and, further, *propositional understanding* of the propositions involved in that particular explanation (understanding "what"). Understanding, then, "flows down" from theory to explanation to individual propositions. In other words, it is in virtue of the relevant objectual (or theoretical) understanding that one has explanatory understanding in the specific problem-context, and in virtue of these understandings together that one has the relevant propositional understanding of the facts involved in the explanation. Knowledge, as it is usually conceived, works differently than understanding. It "flows up" from proposition to theory. This is because knowledge of propositions is the basic form of knowledge. In order to know an explanation (of a phenomenon), one must know the propositions involved in that explanation and know that they are related explanatorily; in order to know a theory, one must know certain explanations and descriptions that are important concomitants of that theory, and know that they are related together theoretically. Both processes—the flow of understanding and the flow of knowledge—are important and intimately related elements of scientific activity. The failure to acknowledge either one would leave some epistemically valuable elements of science unaccounted for.

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. This aggrandizement of propositional knowledge is a traditional dogma of contemporary epistemology. The many successes of this dogma to account for much involved in our epistemic practices has, however, obscured essential facets of epistemology, like learning, conceptual change, and inference. Insofar as these are handled at all in epistemology, they are treated as items to be baked into the propositional mold. Static propositions, however, are the wrong tools for the job, and necessarily force dynamic concepts (like learning, change, and inference) to become mere trivialities (e.g., "learning is the acquisition of new propositions," "conceptual change happens when the intension associated with a concept term changes," "inference is a pattern of propositions where one is related to the others by valid rules") while failing to account for (or even acknowledge) the process itself. It is a fine epistemology for machines, perhaps, but it leaves out much that makes knowledge and other epistemic concepts humanly significant. These aspects, rooted in human experience, should not be obscured or eliminated for the sake of easy analysis.

To illustrate and underscore the point, I conclude with a famous example. The example, Carroll's famous story of the tortoise and Achilles (Carroll, 1895), is meant to show (as I interpret it anyway) that no amount of knowledge can stand in for the ability to infer. The tortoise in the tale is willing to assent to as many premises as Achilles provides him: that P, that $P \rightarrow Q$, that $\{P, P \rightarrow Q\} \vdash Q$, etc. However, the tortoise refuses to assent to the conclusion that Q. That is, the tortoise will not infer that Q, despite the apparent logical compulsion to do so. What lesson is there in this parable? To my mind, it shows that propositional knowledge (including additional theorizing at meta-levels of analysis) by itself cannot fully capture the nature of inference, for the basic reason that inference is fundamentally a practical, skilled activity.[8] If the tortoise fails to understand anything in Carroll's story, it is that he fails to understand how the theory of inference is supposed to be related to the practical activity of making inferences (although, then again, one might suppose that he actually understands it all too well, to the detriment of Achilles...).

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[8] Khalifa claims that the possession of information concerning inferential connections is all that is required to complete an explanatory story, much like Achilles supposes in the story. Although he states that he is willing to concede that the ability to infer may not be fully reducible to knowledge, he dismisses the role of inference in explanatory understanding as "so thin as to trivialize understanding" (Khalifa, 2012, 28). In response, I would say that inference only appears thin and trivial because it is familiar. To a computer, the power to infer would hardly seem thin or trivial!

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