THE EPISTEMIC APPROACH: PROGRESS AS THE ACCUMULATION OF KNOWLEDGE

Alexander Bird
ORCiD 0000-0002-6244-1579

Abstract

I defend the epistemic account of scientific progress as the accumulation of scientific knowledge by showing that it can account for many cases of scientific progress that are not accounted for by the noetic and functional accounts. There are many instances of modest contributions to progress through the addition of new scientific knowledge that does not bring with it new understanding or new exemplary practices. I show that such cases are to be found in the history of biology and of astronomy. Progress can be made also by knowing that some novel phenomenon, such as X-rays, exists, even when that knowledge does not include new understanding or new methods and practices. Keyword: scientific progress.

1 Introduction: approaches to scientific progress

One compelling approach to the nature of scientific progress focuses on truth. The semantic approach says that scientific progress is the accumulation of scientific truth or that it is the increasing proximity of scientific theory to the truth. Alternative accounts of progress can depart from this semantic approach in a number of ways. An anti-realist who nonetheless wants to be able to say that science does make progress will be less demanding than the semantic approach as regards truth. Science can progress without acquiring truth or getting closer to it. Without any truth-related requirement, an anti-realist view will have to be more demanding than the semantic approach in some other respect. Typically such a view will focus on some key feature of

scientific practice that one might regard as the aim or function of science—this is the functional approach. This might be the development and solving of scientific problems. Science progresses when more problems are proposed and solved. This view is more demanding than the semantic approach in that the semantic approach does not require that contributions to scientific progress address scientific problems. The functional approach can be adopted without anti-realist intent. It remains the case that it is more demanding than the semantic approach in this respect.

Other approaches to scientific progress are also more demanding than the semantic approach, but in different respects. The epistemic and noetic approaches both say that scientific progress requires a cognitively more demanding state than belief that is true or truthlike. The epistemic view says that scientific progress requires an increase in scientific knowledge. It therefore requires that developments that contribute to progress have the epistemic justification characteristic of knowledge. The noetic approach says that scientific progress requires an increase in scientific understanding. Quite how the epistemic and noetic approaches relate to one another depends on how one sees the relationship between knowledge and understanding. If, as I do (Bird 2007: 84), one regards understanding as a special kind of knowledge, then the noetic view is just an even more demanding approach than the epistemic approach. On the other hand, if like Dellsén (2016), Hills (2016), or Elgin (2007) one takes understanding to be a different sort of cognitive state, one that does not entail knowledge, then the noetic approach will be more demanding than the semantic approach, but not necessarily more demanding than the epistemic approach.

In my opinion, the fact that the epistemic approach is more demanding than the semantic approach by requiring progressive developments to be justified is an advantage, since adding a true proposition believed for bad reasons to the stock of science is not genuine progress. However, I think that the additional demands placed on progress by the functional and noetic approaches are misplaced. If you think that knowing is a simple, basic mental state (Williamson 1995) then the epistemic view is the simplest of the views on offer. In this paper I argue that the additional complexity demanded by the functional and noetic approaches is mistaken, since discoveries, simply by coming to be known, can add to progress.

2 The noetic and the functional accounts of Dellsén and Shan

What I have called the noetic and the functional approaches are general approaches that encompass more specific accounts that characterise scientific progress in terms of understanding and in terms of the problem-solving function of science respectively. I now turn to the leading specific accounts within each approach, the noetic account of Dellsén (2016 and this volume) and the functional account of Shan (2019 and this volume). These are articulated in detail elsewhere in this volume, and so I adumbrate their accounts as follows:

> **Dellsén's noetic account**
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> Science progresses when there is an increase in scientific understanding. A scientist understands X if and only if they grasp a sufficiently accurate and comprehensive dependency model of X; their degree of understanding of X is proportional to the accuracy and comprehensiveness of their dependency model of X.

> **Shan's functional account**
>
> Science progresses when science proposes more useful exemplary practices. An exemplary practice is useful when it provides a way of defining and solving research problems that is repeatable, provides a reliable framework for looking for solutions to unsolved problems and generates more testable research problems across a wider range of fields.

(For simplicity I will in this paper call these *the* noetic account and *the* functional account, while recognizing that there are other accounts possible within the general approaches they exemplify.)

Without doubt the most important contributions to the progress of science conform to both of these accounts. The chemical revolution of the late eighteenth century led to a new and accurate understanding of the nature of matter and laid down the framework for setting and solving problems that dominated nineteenth century chemistry. Before Lavoisier, the theory of matter was comprised of the vestiges of the ancient four element theory supplemented by the hypothesis of various principles, such as phlogiston, the principle of combustion. Lavoisier's contemporaries were debating, for example, whether water could be transmuted into earth, as suggested by the

fact that water distilled several times would still leave a solid residue when evaporated.[1] Most famously Lavoisier disproved the hypothesis that combustion is a matter of a substance losing phlogiston. The new theory that combustion is a matter of a substance combining with a hitherto unknown substance, oxygen, led to a broader theory of matter: matter is composed of combinations of elements (or of an element in its pure form), where the number of such elements is not small. Clearly this constituted a new understanding of matter and of chemical reactions, and that understanding can be represented as grasping one or more dependency models. At the same time, the chemical revolution established a number of new and useful exemplary practices, most obviously the identification of new elements and showing of which elements particular substances are composed. When supplemented by the law of definite proportion, chemistry became centred on stoichiometry, the science of determining the proportions of reactants in a chemical reaction (and the laws of such reactions), and the related idea that a substance may be represented by a chemical formula.

The discovery of the structure of DNA in 1953 gave scientists not only an understanding of that structure but also a deeper understanding of how it was possible for genetic information to be duplicated in the process of mitosis and to be transferred from one generation to another. The discovery also opened a whole host of research questions in molecular biology, regarding, for example, the details of transcription and the relationship between RNA triples and amino acids, the nature of mutation, and the mechanisms for gene expression, among many others. Two decades after the discovery of DNA began the science and technology of genomics, with the first sequencing of a gene and then a whole organism, MS2, an RNA virus. This in particular initiated a range of exemplary practices in science for identifying and sequencing genes and then for modifying and synthesizing genetic material.

Both the noetic account and the functional account can happily accommodate these undoubted instances of scientific progress. So too, for that matter, can the epistemic account. For the scientific claims of Lavoisier and of Crick and Watson were backed up by careful experiments, detailed analysis of the evidence, and rigorous argument that allowed them to know, for example, that water is a compound or that DNA has a double-helical struc-

[1] This Lavoisier disproved by showing that (after a hundred distillations) the weight of the residue is equal to the weight lost by the glass apparatus he used. By showing that the weight of the total apparatus and water remained the same throughout, he disproved Boyle's claim that fire particles are absorbed by it when heated.

ture.[2] The question for this paper is whether the defining features of the noetic and functional accounts—understanding through grasp of dependency models and the initiation of new fields and techniques of research through exemplary practices—encompass *all* instances of scientific progress, including those that are not as dramatic as the revolutions in chemistry and in molecular biology. Below I argue that neither account can do this. In particular neither can account for the progress made by often smaller advances in the course of normal science. Nor can either account for the progress that is made by a significant but unexpected and baffling discovery. Whereas in these cases there is the accumulation of scientific knowledge, and so there is progress according to the epistemic account.

3 Progress through knowledge acquisition alone

In this section I look at examples from the history of science that were contributions to scientific progress but which do not meet the descriptions required by one or other or both of the functional and noetic accounts described above.

3.1 The discovery of X-rays

In 1895, in one of the best known episodes in the history of science, Wilhelm Roentgen found that with a high voltage he could use a Crookes cathode ray tube to produce a new kind of ray different in important respects from all those hitherto known. These X-rays (or Roentgen rays as they were also widely known) were an immediate sensation among both scientists and the general public. Roentgen himself published three papers on X-rays while scientists across the world published hundreds in the following months and years. There was a great deal of disagreement about the true nature of these rays. Many and diverse theories were proposed; as Alexi Assmus (1995) reports, 'Albert Michelson thought they might be vortices in the ether. Thomas Edison and Oliver Lodge suggested acoustical or gravitational waves.' Assmus goes on to say that opinion settled on the idea that X-rays were electromagnetic in nature. But in the physics of the day that left a lot of room for very different theories, especially as the aether theory of electromagnetism remained dominant. For example, some British scientists, including George Stokes and J. J. Thompson took X-rays to be impulses in the aether, not continuous waves, because X-rays seemed to be able to concentrate energy in a

[2] See, for example, Footnote 1.

way that could not be explained by waves (as demonstrated in their ability to excite electrons). For that reason William Henry Bragg held X-rays to be particles. Roentgen's own view was that X-rays were longitudinal waves (like sound waves).

In 1901 Roentgen was awarded the first Nobel Prize in Physics for his discovery. This was before the correct theory of X-rays was known, following work by Johannes Stark, Max von Laue, and Charle Barkla among others. In particular, the development of the quantum theory was required before the concentration of energy effect could be reconciled with the idea that X-rays are also electromagnetic waves of the same kind as visible light except of much higher frequency.[3] The discovery of X-rays satisfies neither the functional nor the noetic account of progress, despite being a clear example of a contribution to progress.

The discovery of X-rays was not itself a useful exemplary practice. For sure, the discovery of X-rays led to exemplary practices, both within science and outside science. Very quickly X-rays were being used in medicine and also in engineering. It took longer before X-ray crystallography was developed by the Braggs as an exemplary practice in science *ne plus ultra*. But it was not these that made the discovery of X-rays a contribution to progress, it was the discovery itself. The 1901 Nobel prize was given to Roentgen 'in recognition of the extraordinary services he has rendered by the discovery of the remarkable rays subsequently named after him'. (X-ray crystallography was developed after 1901 and merited its own Nobel prize, in 1915.)

Nor did the discovery of X-rays involve a sufficiently accurate and comprehensive dependency model of X-rays. In 1901 several competing models of X-rays were on offer, none of them either accurate or comprehensive, since this date preceded Einstein's theory of the quantisation of light. What scientists knew in 1901 was that X-rays were important. But what they were remained largely a mystery. It is true that experiments had revealed a number of dependency relations. But for the reasons given, no-one was able to accommodate them all in a satisfactory model. It is also true that all the physicists aimed to find that model and show it to be correct. But that shows only that understanding is a particularly valuable kind of progress sought by scientists, not that it is the only kind of progress.

[3] Stark was a committed Nazi who enthusiastically supported the removal of Jewish scientists from their posts. It is ironic therefore that his contribution to the history of X-rays was that he was among the first to accept Einstein's proposal regarding the quantisation of light and the first to apply it to X-rays.

In short, Roentgen's discovery of X-rays was a celebrated contribution to scientific progress because after 1895 scientists knew that these interesting and important rays existed whereas before then they were ignorant of their existence. Progress here was made by the addition of knowledge and nothing more.

3.2 Astronomy, star catalogues and the discovery of comets

Astronomy is one of the oldest sciences, with many societies attaching social and theological significance to the stars and planets as well as finding them intrinsically interesting. In particular the role of astronomy in constructing calendars, themselves important in many aspects of life from agriculture to religion, motivated study of the stars. Mayan astronomy, for example, was used in the organisation of religious rituals and in the planning of cities. The highly accurate data produced in their observatories enabled the Maya to distinguish the solar year from the tropical year and to predict eclipses. Indian astronomy also goes back thousands of years. It benefitted from contact with Greek astronomy following the invasion by Alexander the Great, and flourished especially in the mid first century with the work of Aryabhata and Brahmagupta, which in turn influenced Islamic astronomy.

It is clear from looking at these texts that Mayan, Indian, Greek, and other astronomers had a great deal of knowledge. It is not so clear that they had a great deal of understanding. For example, both Eratosthenes and Aryabhata gave accurate figures for the circumference of the Earth. It is true that they will have to have had mathematical understanding in order to calculate their figures, but that understanding alone does not account for the totality of their scientific achievement. For the latter involves them actually producing their numerical estimates from the data that they or others collected. Their understanding of the mathematics plus knowledge of the data enabled them to make the accurate calculations of the circumference, and the latter knowledge is *itself* a contribution to scientific progress. The noetic view, it would seem, has to deny that this knowledge is itself progress, and limit the latter to the mathematical understanding that preceded it. Ptolemy likewise was able to predict the observed positions of the planets with accuracy using his model of planetary motion. But this geocentric model was a highly *inaccurate* dependency model. The epistemic view takes Ptolemy's work to be progressive in virtue of the knowledge of the observable motions of the planets it provided, whereas the noetic view seems to deny that it constitutes any progress at all.

Hipparchus, the greatest of the ancient Greek observational astronomers, created one of the first and most important star catalogues. A star catalogue

is a list of the fixed stars and their positions in the sky. It might also include a naming system and a record of the brightness of the star. Hipparchus's catalogue was adopted (perhaps fraudulently) by Ptolemy and thereby became the basis of subsequent star catalogues, such as the *Book of Fixed Stars* of the Persian astronomer Abd al-Rahman al-Sufi. Tycho Brahe, with his assistant, Johannes Kepler, drew up a new catalogue, the basis of the Rudolphine tables. The latter, which was both a star catalogue and the means of predicting planetary motions, incorporated 1,005 stars recorded by Brahe and Kepler as well as several hundred from Ptolemy (and so from Hipparchus). It also included stars observed by Johann Bayer, who himself produced the star catalogue and atlas, the *Uranometria Omnium Asterismorum*, which was the first of its kind to include stars observable only in the southern hemisphere, thus covering the whole celestial sphere. Bayer introduced a system of nomenclature for stars, using a Greek letter and the constellation in which it is found, hence Alpha Centauri, Gamma Cephei, and so on. The next great catalogue was drawn up over several decades by John Flamsteed, who introduced a new system of designation employing numbers instead of Greek letters, also still in use today. By using a telescope Flamsteed was able to increase the number of stars recorded, three times the number Tycho had listed, including many stars too faint to be seen with the naked eye. Following the tradition of over two thousand years, subsequent astronomers corrected and added to Flamsteed's *Historia Coelestis Britannica*. Perhaps the most significant astronomer to do so was Caroline Herschel. Her corrections and additions to Flamsteed's catalogue were important to her and her brother William's project of searching for comets, nebulae, star clusters, and double stars. The Herschels' catalogue became the basis of the *New General Catalogue* (1888) of nebulae and star clusters, itself revised and updated to the present day. Caroline herself was able to identify numerous comets, but the most important discovery was a by-product of this activity, when she and William discovered the planet subsequently known as Uranus (which they initially took to be a comet).

The process of cataloguing stars is a contribution to scientific progress. That it is so is easy to see on the epistemic account (and on the semantic account). There is an accumulation of knowledge of the existence, position, and brightness of stars. This knowledge also increases as the catalogues become more accurate and when improvements in technology allow for greater precision in what is already known. Yet neither the noetic nor the functional views can account for this progress adequately. Clearly, adding more stars to the catalogue or recording the position and brightness of existing ones with greater precision and accuracy adds nothing in terms of understanding. There is no dependency model here, and so no improvement in a grasp of such a

model. The only increase in understanding in the story told above came when Anders Lexell calculated the orbit of Uranus to confirm that it was indeed a planet. That too was a contribution to progress. But it was not the only one. Knowing that this was a new celestial object that was not a star was in itself a major advance in astronomy.

The story does include several instances of the addition of useful exemplary practices, such as the introduction of the telescope and of the naming systems of Bayer and Flamsteed. Numerous smaller advances were made that enabled astronomers to record the positions of stars more accurately or simply to identify stars more easily. One such innovation was made by Caroline Herschel, who reorganised Flamsteed's catalogue, so that stars are listed not by constellation but by North Polar distance (Hoskin 2011: 193). But for the most part the progress in astronomy described above was made not by the addition of new useful exemplary practices but by the application of existing practices laboriously and meticulously, again and again.

3.3 Natural history after Aristotle

The science formerly known as natural history was built on three basic practices: the careful observation of flora and fauna in their habitats, the collection and conservation or preservation of samples, and the naming and classification of species. These practices reinforced one another. For one scientist's observation of an animal could contribute to science only if other scientists know which animal the first is talking about. Samples might be conserved by breeding, such as the plants brought from all over the world and then bred at Kew Gardens. Or they might be preserved through taxidermy and other such techniques, giving us the glass cases full of carefully mounted and labelled insects and other animals that one can see at the Natural History Museum in Kensington. Such samples aided the shared recognition of species. Not everybody could have access to the physical samples, so printing became an important adjunct to collection. Kusukawa (1997; 2011) describes how in his *De Historia Plantarum* (1542), the Tübingen Professor of Medicine, Leonhart Fuchs compared the description of a plant given by the ancient Greek author Dioscorides in his *De Materia Medica* to a picture in his own book, to establish that they are the same plant, and was thereby able to add his own observations to those of Dioscorides in order to provide a more complete knowledge of this species.

The practices of observation, collection, and classification are all to be found in the work of Aristotle. Aristotle spent several years recording his observations of the fauna on the island of Lesbos, while his friend and suc-

cessor as the scholarch of the peripatetic school at the Lyceum, Theophrastus, worked on its flora. Among his thousands of careful observations Aristotle described the life-cycle of the cicada, noted the changing colours of octopuses, and recorded the growth of different kinds of fish from their eggs. He removed sections from the shells of chickens' eggs to see how the parts of the embryo developed over time (although he drew the wrong inference from what he saw). Some of the samples with which he worked had been sent to him from Asia by Alexander the Great. Aristotle named and classified over five hundred distinct animal types. Observing that dolphins gave birth to live young, he classified them with the quadrupedal mammals.

It is true that Aristotle was searching for causal relations among what he saw, although what he achieved in this respect was limited. In addition to the obstacles to establishing cause and effect in biology, Aristotle was limited by his own theories, such as his own theory of causation. He did not carry out experimental biology, in part because his distinction between natural and violent motions implied that what is seen under experimental conditions would not tell one about what things are like under normal conditions. So his ability to generate accurate dependency models was very limited. Although we know some of Aristotle's particular techniques, such as that with the chicken's eggs and dissections of animals, for the most part he did no more than observe carefully and systematically. So there is some but not a great deal in his work by way of novel exemplary practices. Furthermore, even if his biological practices were exemplary, they did not in fact serve as exemplars to any great extent, since his work and that of Theophrastus was not greatly added to in subsequent generations.[4] So it is difficult to see a great deal in Aristotle's *Historia Animalium* that represents progress according to either the noetic or the functional accounts. Aristotle himself distinguished between the *what* and the *why* in science. Only the latter counts as progress for the noetic view of progress. But it is instead our knowledge of the former that is greatly enhanced by Aristotle's work. That knowledge is an important contribution to science whether or not it contains solutions to scientific problems or exemplars of what a problem is and how it should be solved.

The next significant advances in zoology and botany (medicine aside) occurred in the sixteenth century and gathered pace in subsequent centuries. It was not until the work of Darwin and Mendel that biologists had anything like a grand explanatory theory that could be used to develop dependency

[4] Applications of zoology and botany to medicine are the exceptions to this, providing new knowledge of anatomy and of *materia medica* (plants used for medical purposes).

models. And the scientific techniques involved were essentially the same as those used by Aristotle—fundamentally, keen observation and careful record keeping. Most naturalists were engaged in the study of morphology—the detailed description of the physical appearance of animals and plants—not least because morphology was the principal basis for naming and classification. Some, like Aristotle, were also interested in ethology, the study of animal behaviour. Edward Jenner was elected a Fellow of the Royal Society not for his work on vaccination but because he was the first to describe the behaviour of fledgling cuckoos in detail. Aristotle himself had noted that cuckoos lay their eggs in the nests of smaller birds. But before Jenner it was believed that it was the adult cuckoo that ejected the eggs of the foster-parent birds. Jenner's patient observations, recorded in a paper of 1788, demonstrated that it is the young cuckoo itself who pushes out the eggs and that the young cuckoo has a depression between its wings that enables it to do so. Perhaps the best known naturalist of Jenner's day, subsequently at least, was Gilbert White. White was the epitome of a certain type of naturalist—the country parson who studied and recorded his environment in detail and shared his findings with other scientifically minded colleagues, most famously in his letters to the leading British zoologist of the day, Thomas Pennant, and to the vice-president of the Royal Society, Daines Barrington. The letters were published as *The Natural History of Selborne* (White 1789). The latter was hugely influential—the elderly Charles Darwin highlighted its significance in his own development as a young naturalist. These letters are full of novel facts, for example the many facts deriving from the first bird census, one of White's innovations, including those observations that helped establish the fact of bird migration. And the fact that the bird known as the willow wren is in fact three species (the willow warbler, the chiffchaff, and the wood warbler), which he determined largely through differences in their songs (West 2021). And so on for hundreds of other valuable observations.

It is easy to find important elements in the work of White, Jenner, and other naturalists that satisfy the noetic and functional accounts of scientific progress. One can describe the nesting behaviour of the cuckoo and the migration of martins in terms of dependency relationships. As Britain's first ecologist, White noted many important connections of this kind. His famous lines on the earthworm, which particularly influenced Darwin (who shared his enthusiasm for this animal), establish the dependency of both vertebrates

and plants upon it.[5] White's bird census is now a standard methodological tool for ornithologists. He also pioneered the use of pre-printed notebook for the systematic recording of observations, designed by Barrington. So his work certainly did employ new and useful exemplary practices.

Nonetheless, the contributions to understanding and to the development of exemplary practices made by these naturalists were small in comparison to the accumulation of knowledge that they added to science. It would be odd to think that their careful descriptive work added nothing to scientific progress in itself. One might also consider the voluminous and even more influential work of Alexander von Humboldt. Humboldt did make important methodological advances, but these made up only a small proportion of his work on the biogeography of Latin America and other regions of the world. Similarly, he was keen to understand the flora, fauna, landscape, climate, and people of these places and their interrelations. Yet, working before Darwin, his explanations and theories were only partially successful. Humboldt's significance for the progress of science does not rest on these alone. Rather the careful descriptions, including quantified analyses, of what he discovered were a major part of what made his reputation and what made his work important.

4 Mere data or observational knowledge?

It should not be thought that these less glamorous additions to science are always mere data gathering, important only as fuel for scientific progress, not constituting progress itself. We can make a distinction between *data* and *observations*. Let us consider what happens when a scientist makes an observation. Often an observational practice will be subject to random error, so no single measurement can be taken to be an accurate representation of the true value. Precisely this problem arose in the determination of the orbits of the minor planets in the early nineteenth century, following the discovery of Ceres by Father Giuseppe Piazzi in 1801. And it was to solve this problem that Gauss developed the method of least squares and the theory of the normal distribution. The astronomer will record multiple measurements in her

[5] White (1789: 172) writes that "Earthworms, though in appearance a small and despicable link in the chain of nature, yet, if lost, would make a lamentable chasm. For, to say nothing of half the birds, and some quadrupeds, which are almost entirely supported by them, worms seem to be the great promoters of vegetation, which would proceed but lamely without them, by boring, perforating, and loosening the soil …and, most of all, by throwing up …worm-casts, which, being their excrement, is a fine manure for grain and grass."

notebooks. These we may call her *data* (Bogen and Woodward 1988: 308). As noted, none are correct assertions about the quantity being measured and so none can be regarded as knowledge of such a quantity. So it is correct that the mere collection of data (thus understood) is no contribution to scientific progress.

Armed with sufficient data, the astronomer will then calculate the mean value of the quantity (or an orbit that satisfies the least squares condition etc.). Now she has a value that can be regarded as likely to be the correct one, within a margin for error. Should she have carried out this process with sufficient rigour, then the resulting propositions concerning the value will be knowledge concerning the correct value of the quantity. These items of knowledge are her observations. And adding these to the stock of scientific knowledge is a contribution to the progress of science.

It might be replied that the data points might too be might generate knowledge, because they also will mostly be correct within a suitable (rather wider) margin for error. That margin for error, though, will typically not be known in advance—whereas the one for the finally recorded observation, the mean value of all the data points, can be calculated from the data itself. In any case, there are other examples where the data points clearly concern only the apparatus and process of observation and are not observations themselves. The LIGO detectors enabled an observation of a gravitational wave by measuring the strain in the arms of the detectors using an interferometer. That strain data would reflect both any gravitational wave plus environmental disturbances to the detectors (e.g. seismic activity). Those environmental disturbances are also measured independently. The strain data are taken to indicate a gravitational wave when a signal in the strain data is deemed to be a highly improbable occurrence given the environmental disturbances alone. So the strain data themselves cannot be thought to be measurements of anything outside the apparatus, not even within some margin for error. It is the inferred existence of the gravitational wave that constitutes the knowledge produced by the LIGO apparatus, and which in the scientists' parlance, constitutes the observation.

Many philosophers will balk at calling the latter item of knowledge an 'observation' since is is the product of inference, not of direct perception. Scientists, on the other hand, are entirely content to talk of the observation of imperceptible entities, such as quarks and magnetic fields, where that observation does involve inference. The present point, however, does not concern the correct analysis of 'observation'. Rather it is to point out that there is a principled way of distinguishing between 'mere' data, whose collection is not a contribution to scientific progress, and the result of processing that data to

produce knowledge, which is a contribution to scientific progress. And the knowledge discussed in this paper, from knowledge of the existence of X-rays to knowledge of the correct position of a star to knowledge of the differences between distinct species of warbler, is all of the latter type. These discoveries and piecemeal additions to scientific knowledge are not mere data.

Above I remarked that Aristotle himself made a distinction between the *what* and the *why*. For example, he writes (Aristotle/Nussbaum 1985):

> Clearly there needs to be a study of all of these questions about animal locomotion and any others of the same kind; for that these things are thus is clear from our inquiries into nature; the reason why must now be investigated.

Science, according to this view, commences by establishing knowledge of the facts about what there is and what it is like (*το 'οτι*; to hoti), and then proceeds to ask why things are thus and so (*το διοτι*; to dioti).[6]: While understanding is an important goal for science, it is not all of science. Gaining knowledge of the what of things is its own scientific investigation and is itself a contribution to science's progress.

5 Conclusion

Without doubt the most important contributions to the progress of science are those that add to our understanding and which expand our scope for setting and solving further scientific research problems.[7] Our initial examples of the discovery of DNA and the chemical revolution demonstrate this amply. Nonetheless, it would be fallacious to infer that what characterises the best examples of scientific progress must be present, albeit to a lesser degree, in all instances of scientific progress. Some worthwhile science is more prosaic, adding to the detail of our picture of the world, without deepening out understanding or opening new avenues for investigation. Knowing which species of flora and fauna there are or which stars, planets, and comets exist may be mundane by comparison with the greatest advances of science, but they are advances nonetheless. The naturalists and astronomers of the eighteenth and

[6]Lennox (2009) argues that Aristotle's *History of Animals* is itself a work of *το 'οτι* investigation, while it is his *Parts of Animals* and *The Motion of Animals* are the subsequent *το διοτι* investigation. If so it is clear that Aristotle thought that the former, the investigation of the *what* of things is itself a worthwhile scientific goal.

[7]This, I maintain, can be explained within the epistemic approach (Bird 2022).

nineteenth centuries, like Aristotle and Hipparchus, in making careful and systematic observations of the world were not engaged in a fruitless or unscientific pursuit but were, by adding to the stock of scientific knowledge making small steps in the advancement of science. In his autobiography, Darwin asserted that Humboldt's *Personal Narrative* and John Herschel's *Introduction to the Study of Natural Philosophy*, were the two books that had most influenced him 'stirring up in [him] a burning zeal to add even the most humble contribution to the noble structure of Natural Science' (Darwin 1958: 67–8). While the greatest scientific advances typically do add to our understanding and do furnish science with new exemplary practices, much of the work of science is not of this kind. To use Darwin's expression, even the most humble additions to scientific knowledge are also thereby contributions—even if only humble contributions—to scientific progress.

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