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In the issue of *Science* for 1 July 2005 the editors celebrate the journal's 125th anniversary by noting 125 *unsolved* problems in contemporary science. Many of these problems could not have been formulated 125 years ago; here are some examples:

- What powers quasars? (79)
- Why is there more matter than antimatter? (80)
- Does the proton decay? (80)
- Are neutrinos their own antiparticles? (81)
- What is the ultimate efficiency of photovoltaic cells? (84)
- Can we predict how proteins will fold? (86)
- What roles do different forms of RNA play in genome function? (87)
- What is all that "junk" doing in our genomes?(88)
- How do prion diseases work? (91)
- Do deeper principles underlie quantum uncertainty and nonlocality? (98)
- Does the Standard Model of particle physics rest on solid mathematical foundations? (102)

The editors also note that many of the problems they discuss "will undoubtedly spawn new questions" (78).

As these examples illustrate, discovering the truth about a subject is often not an option at a particular point in history. Sometimes truth will not be available for a long time. It was a long journey to the germ theory of disease and to quantum theory—which may not be the last word in their respective domains even though they have provided such practical offshoots as antibiotics and transistors. Indeed, the path to justified true beliefs is often paved with justified false beliefs that prepare the way. Since understanding the pursuit of truth should play a central role in epistemology, an account of the epistemic significance of justified false beliefs is central to this subject. I will attempt to contribute to this endeavor here in three steps. First, I will consider some of the ways in which false beliefs contribute to the pursuit of true beliefs and thereby acquire epistemic value. Second, I will discuss the special role that justification plays among our epistemic values. Third, I will consider the significance of these two discussions for our overall understanding of epistemic value.

I want to begin by recalling some familiar features of Newtonian mechanics—which provides a clear example of a set of well-justified false beliefs that played a key role in the further development of physics. Given our recognition that Newtonian mechanics does not provide a true account of the physical world, the fact that the theory is *testable* leaps to the mind.[1] But many claims are testable. An important feature of Newtonian mechanics is the way it provided the basis for the research that led to its being challenged and superseded. There was, for example, an anomaly in the orbit of Mercury only in contrast to the Newtonian predictions. More generally, in conjunction with appropriate auxiliaries, Newtonian mechanics yields highly precise predictions about many aspects of the physical world. Some of these predictions led to a deeper understanding of the physical world, while others posed challenges to Newtonian theory and led to a search for better candidates for a true account. This ability to *guide research* is central to the epistemic value of Newtonian mechanics. For example, Newtonian mechanics tells us that whenever we find a celestial object moving in a non-linear path, some force is acting on that

[1] At various points in this paper I will talk about propositions and about theories. For present purposes a theory should be considered a set of propositions. Newtonian theory thus consists of four propositions: the three laws of motion plus the gravitation law.

object; this conclusion would not have been drawn at an early stage in the development of physics. In addition, Newtonian mechanics tells us a great deal about the properties of allowable forces since they must conform to Newton's second and third laws. If we have reason to suspect that a gravitational force is operating, Newtonian mechanics provides an account of the factors involved in determining the strength and direction of this force. These considerations guide our attempts to find the appropriate force, and the outcome of such attempts can either enhance the theory's justification or provide reasons for reconsidering whether the theory is true. As a result, testability and the ability to provide specific guides for research are intimately related.

Testability and the ability to guide research are related to another aspect of science. Scientists regularly seek to extend their theories into domains that were not considered when they formulated those theories. Such extensions can lead to new tests against new kinds of evidence—often using new kinds of instrumentation. Contemporary astrophysical theories, for example, must deal with evidence collected throughout the electromagnetic spectrum and in the realm of elementary particles. The first solar-neutrino experiment, to take one important case, was developed to test a widely accepted account of stellar-energy generation. This experiment was proposed just a few years after physicists became confident that they could detect neutrinos (c. 1958) and the experiment allowed them to test a consequence of a prevailing theory that had never before been tested. The experiment assumed the available account of neutrinos from particle physics and looked for neutrinos in physical situations in which they had not previously been sought. The first outcomes of this experiment clashed with predictions and motivated the development of further experiments that can detect neutrinos with a wider range of energies than the original experiment, and that provide more precise information about neutrinos. The current view of the outcome of these experiments is that the astrophysical theory originally under test has been sustained, but the standard account of neutrinos—in particular, the thesis that neutrinos have no rest mass—has been undermined. Further consequences of this result are currently being tested and we do not yet know how far these results will ripple through particle physics. In other words, while the understanding of neutrinos that was available in the early 1960s played a central role in developing and interpreting these experiments, that understanding has been undermined in ways that may point to unanticipated features of the physical world. In effect, particle physics and astrophysics were extend into each other's domains. Theories that are *extendible* in this way have greater testability and a greater ability to guide research than theories that are limited to a narrow domain.

Returning to Newtonian mechanics, this theory also provides the basis for wide-ranging engineering practice in spite of its being false. We now understand that this occurs because there are many situations in which the quantitative results that we get from Newtonian mechanics are very close to the results we now believe to be correct. Just how far we can go with Newtonian mechanics depends on both our current purposes and the precision of the instruments we are using. Sometimes a false theory that has approximately true consequences and can be easily applied is more useful than a true theory that cannot be easily applied. There is no point to considering the curvature of the earth when building a patio, although curvature must be taken into account when building a transcontinental highway. We can include the ability to provide *practical applications* among the epistemic values at least to this extent: when a theory provides a guide to practical applications, we have an additional set of testable consequences that can enhance or undermine our grounds for believing that theory.

In addition to practical uses, in a particular historical situation a false theory will sometimes provide better support for research than its true alternative. In the early days of Copernicanism, for example, the failure to observe the stellar parallax that should result from the earth's motion about the sun constituted a major problem. Since the amount of parallax to be expected is inversely proportional to the distance to the stars, the Copernican response was to maintain that the stars were sufficiently far away to prevent the appearance of parallax. This was considerably farther away than was generally believed and implied a vast empty space between the outermost known planet, Saturn, and the stars. At the time this provide a further objection to the Copernican thesis. But the postulated distance was much too *small* because the distance from the earth to the sun is vastly greater than the best available estimates at the time. Copernicus, Tycho, and Galileo all estimated this distance as less than five-million miles while Kepler thought that it was closer to six million miles.[2] The modern value for the average earth-sun distance is ninety-three-million miles, which yields a distance to the stars that is more than fifteen times that of the surprisingly enormous distance required by sixteenth- and seventeenth-century Copernicans. If the correct value of this distance had been known the argument against a moving earth would have been strengthened and might well have hampered the development of astronomy at that time. In a similar way, Pasteur's nineteenth-century conclusion that inorganic matter cannot produce life had a positive effect on the development of biology, even though this claim was later rejected.

These remarks suggest that while truth is an important epistemic value, it is one epistemic value among others. Testability, ability to guide research, extendibility, and the provision of practical applications are epistemic values that can characterize both true and false theories. A false theory that has these features will thus possess epistemic value that may not be shared by the true alternative—and this raises the question whether the overall epistemic value of some false beliefs exceeds that of some true beliefs. We can take a step towards answering this question by considering ways in which different claims are justified. In the sciences, for example, we typically require a much higher level of justification than we do in everyday life. Many everyday beliefs—including many true beliefs—neither receive nor require a great deal of explicit justification. In such cases, reliabilism provides a viable approach to understanding justification. On this account, justification requires only that beliefs be arrived at by a reliable process. The justified believer need not be aware of this process, its mode of operation, or the source of its justifying power. This feature of reliabilism is often presented as a virtue of the theory since it allows us to admit a wide variety of knowledge among ordinary folk, young children, and even other animals. But reliabilist justification is not acceptable in science. A scientific paper that put forward a claim and noted that the claim is justified if it was arrived at by a reliable process would be rejected without bothering referees. At the very least, the authors must provide an explicit account of the justificatory processes and an explanation of why they are reliable before scientists will consider the proposal as a candidate for a true claim. We also demand a high level of explicit justification in practical situations that have consequences for our health and safety. We demand, for example, that drug companies provide a great deal of explicit evidence of safety and efficacy before they are allowed to distribute their products. Bridge and airplane designers face similar demands. If we applied these standards to everyday beliefs, many paradigm examples of true everyday beliefs would fail to qualify as justified.

Our discussion suggests that we should consider a contextualist account of justification which allows for different standards of justification in different situations. Annis provides a nice example:

> Suppose we are interested in whether Jones, an ordinary non-medically trained person, has the general information that polio is caused by a virus. If his response to our question is that he remembers the [news]paper reporting that Salk said it was, then this is good enough. He has performed adequately given the issue-context. But suppose the context is an examination for the M.D. degree. Here we expect a lot more. If the candidate simply said what Jones did, we would take him as being very deficient in knowledge. Thus relative to one issue-context a person may be justified in believing *h* but not justified relative to another context. (1978: 215)

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[2]The distances were often expressed as a multiple of the radius of the earth, which was known to a very good approximation since antiquity. Thus conversion to units familiar to us is straightforward. See van Helden (1986) for details and discussion.

But let us compare Jones, whom I will assume is not a candidate for an M.D., with Smith who is and who meets the standards of justification appropriate for that context. We can step back from these contexts and note that the epistemic quality of Smith's justification is superior to that of Jones. If Jones were to learn more about the cause of polio, the epistemic quality of his justification would be improved. This suggests that justification comes in degrees. Even if the requirements for being justified vary with context, we can compare degrees of justification across contexts. I will develop the significance of this thesis in a moment, but first I want to address two replies to the suggestion that justification comes in degrees.

One reply is to adopt an absolutist account of justification: there are criteria that must be met for a claim to be justified, and these are independent of context. A claim is justified if and only if it meets these criteria. But this proposal faces serious objections. One way of implementing this approach is to adopt a relatively low standard for justification. We might hold, for example, that Smith and Jones both have justified beliefs that polio is caused by a virus on the basis of what they read in the newspaper. Yet as Smith acquires the additional information required for her medical degree, she improves her epistemic situation. We might resist describing her enhanced epistemic state as possession of a better-justified belief, but however we describe it, her new state is epistemically superior to her previous state. If we set the bar for justification too low, we will find that justification is not sufficient for accepting scientific claims or for acting on our beliefs in many practical situations.

A second reply is that this talk of adopting standards of justification is off the mark. The philosophical task is to clarify the concept of justification that we already have, not to legislate what this concept ought to be. But this response also will not do. It is quite possible that the everyday concept of justification embodies standards that are too low to be acceptable in the sciences. There is no *a priori* guarantee that a concept that has presumably existed across cultures and throughout human history will adequately embody the standards of, say, modern experimental and statistical techniques. In many cases the development of science has raised the standards for belief-worthiness. For example, it took time before researchers came to understand the dangers of unintended bias in gathering and analyzing data. Once understood, this led to the use of blind experimenters and, where appropriate, blind experimental subjects. Double blinding is now the gold standard in much medical and psychological research and has also been applied in physics. (See, for example, Franklin 2002, Ch. 6, Kaptchuk 1998, Klein and Roodman 2005.) Other examples include Bessel's discovery in the nineteenth century that a standard technique in which an astronomer watches a moving object through a telescope while listening to a ticking clock to determine when an object reaches a particular point in space gave results that varied significantly among observers. Before this variability was discovered, one astronomer lost his job because he consistently got different results than his boss (Boring 1950, Ch. 8). In twentieth-century-high-energy physics, experimenters increased the statistical cut-off for new discoveries after finding that a previously accepted cut-off too often produced statistical artefacts (Franklin 2002: 5-6).

Given that justification comes in degrees, let us note three respects in which degrees of justification may vary. First, a specific claim can be better justified for one believer than for another. Second, a specific claim can be better justified for a single believer at different times. Third, degrees of justification may vary across quite different beliefs. For example, the overall evidential support for Newton's second law at, say, the end of the nineteenth century, was considerably greater than that for Copernican astronomy at the end of the sixteenth century. In addition, the justification for Newton's second law at that time was also considerably greater than that for many everyday beliefs about other people's motivations, even if the latter were, in fact, true.[3] The greater justification of Newton's law

[3]Recall that Newton's second law is false because mass is not constant and because force and acceleration need not be in the same direction across reference frames.

derived from its having been successfully applied in diverse situations including collisions of particles, movements of planets, and myriad practical applications. Even if everyday beliefs do not require extensive testing to be justified, the point remains that Newton's law was better justified than some true everyday beliefs.

This situation raises a fundamental problem about the significance of justifications that support false beliefs. While, we have seen, false beliefs sometimes play a positive role in the acquisition of true beliefs, this does not always occur, and it is unclear how often it occurs. Moreover, there may be cases in which research based on a belief that is not justified in a particular situation would give a more effective means of moving towards a true belief. Within the limits of this paper I suggest that we should prefer justified beliefs because they provide a coherent, organized basis for research. If we do not focus on justified beliefs, we wind up with too many paths to pursue and no reasonable way to apportion our limited cognitive (and often economic) resources. To be sure, true beliefs are valuable for their own sake and take on additional value when we must act on our beliefs. But, as Plato noted in *Theaetetus*, if I stumble into a true belief without any reasons for adopting it, I can just as easily stumble out of it. *High degree of justification* is thus another epistemic value that can be shared by true and false beliefs.

I now want to introduce another theme by focusing on true beliefs and considering an additional way in which their epistemic value may vary: some truths are more significant than others.[4] Let us consider two ways in which such differences in significance can occur.

The first derives from Popper's attempt to specify ways in which some propositions have greater empirical content than others. Popper's general approach was to argue that some propositions are more easily falsifiable than others and then identify a higher degree of falsifiability with higher empirical content. We can see the motivation for this by comparing the following two propositions:

P1. Pat is more than six-feet tall.

P2. Pat is six-feet-one-inch tall.

Intuitively, P2 carries more information than P1 and there is a clear sense in which P2 is more falsifiable than P1: any measurement that falsifies P1 also falsifies P2 while there are many measurements that falsify P2 but not P1. Another situation, one that Popper explored (1992, Ch. 6), concerns universal generalizations. Consider:

P3. All orbits of heavenly bodies are circles.

P4. All orbits of planets are circles.

P5. All orbits of heavenly bodies are ellipses.

Popper noted that P3 has greater content than P4 because P3's subject class is wider, while P3 has greater content than P5 because P3's predicate class is narrower (circles are ellipses in which the two foci coincide). Both sets of examples illustrate a general principle: If p and q are not equivalent but p entails q, then p is more falsifiable than q and thus has greater empirical content. In all of the cases mentioned, p is more falsifiable than q because the set of outcomes that will falsify q is a proper subset of the set of outcomes that will falsify p. Popper never succeeded in developing a measure of content that would apply in cases where this relation does not obtain; I will not pursue this project here.

Consider now a second way in which a proposition can have high significance: it can have multiple links to other propositions. The claim that no physical motion can exceed the velocity of light in a vacuum (henceforth c) is central to special relativity (SR) and provides a good example of a current candidate for a true proposition with such links. It may be useful to emphasize the import of this claim. Suppose we launch a rocket ship from the earth that achieves a velocity of $.75c$ with respect to our planet. This ship then launches a daughter ship in the same direction that achieves a velocity of $.75c$ with respect

[4] I am not suggesting that truth come in degrees. See Kitcher 2001, Ch. 6 for a different approach to significant truth.

to the mother ship. The velocity of the daughter ship with respect to the earth cannot be the sum of these two velocities since that would exceed *c* (SR deals only with relative velocities). As a result, SR forces us to adopt a new rule for combining velocities—one which ensures that no sequence of summed velocities will ever be greater than *c*. Let the two velocities be *u* and *v*. According SR the combined velocity is $(u+v)/(1+uv/c^2)$. This result is entailed by the postulates of SR, which include the light-speed principle; Einstein derived it in Section 5 of his first paper on SR (1998). The massive evidence that supports SR also supports this new rule for combining velocities. The role that *c* plays in this rule is particularly striking and is just one of many instances in which formulas from classical physics are replaced with new formulas in which *c* plays a key role. There are also cases in which the light-speed principles requires a new formula although *c* does not occur in that formula. The formula for calculating a recession velocity from a red shift is one such example. This is usually expressed as the ratio of the recession velocity to *c*, and symbolized as β. Using *S* to symbolized the red shift, classically $\beta=S$. But this cannot be correct because there is no limitation on the value of *S* while SR requires that β be less than one. The relativistic formula is $\beta=(S^2-1)/(S^2+1)$. We can describe the overall situation by saying that the light-speed principle has high *systemic import* in SR. In classical physics *c* is just one velocity among others with no special significance, but in SR the light-speed principle is deeply embedded in our current understanding of how nature works. Its acceptance forced major revisions in deeply ingrained intuitions from earlier physics and everyday thought. If it were to be refuted, the result would be revolutionary. Many true everyday beliefs—such as the proposition that states the distance from my home to my favorite supermarket—have little systemic import.

Cases of high systemic import are not confined to mathematical subjects. Discovery of the chemical structure of DNA and its role in heredity has impacted many fields of research. It has, for example, introduced a new kind of evidence into studies of the evolutionary history of species; it has legal implications in criminal investigations, and possible medical consequences that are currently a topic of major research. The research leading to the DNA structure also opened one aspect of Darwinian theory to a major test. If it had turned out that the chemical basis of human heredity is different from that of any other species, then we would have had major support for the view that the history of human life is unique. As it is, the outcome has supports the unity of life on this planet.

There may be other properties that contribute to a proposition's significance besides high systemic import and high empirical content, but these will suffice for the present. Note, however, that both properties characterize a proposition independently of its actual truth-value. In the case of false propositions, they contribute to our ability to discover that a proposition is false in ways that may point to new candidates for high-significance truths. Newton's second law is an example of a false proposition with high significance; I want to return to this case to develop another point about the pursuit of truth.

The formulation of Newton's second law required some major conceptual innovations. These, in turn, became steps to further conceptual innovations needed to formulate some of our current best candidates for true beliefs about the physical world. Two such innovations were central in this case. First, Newton introduced the concept of mass as distinct from weight. Mass is an intrinsic property of a physical object that remains the same whatever its location in the world and whatever its state of motion. The familiar phenomenon of weight was then rethought as a relational property: the gravitational force between the planet Earth and the object of interest. Moreover, this everyday phenomenon now became viewed as a special case of a more general phenomenon: the existence of a gravitational force between any two material objects. From this new perspective, my weight changes as my distance from the center of the earth changes. In addition, my weight will be different if I travel to the moon or another planet. Unlike prior thinking about weight, this generalization has high empirical content and systemic import.

Second, Newton introduced a concept of acceleration in which change of speed and change of direction are instances of the same phenomenon. By way of contrast, Galileo held that motion in a circle at a constant speed is non-accelerated motion (1967: 31-2); Descartes explicitly argued that change of direction and change of speed are different phenomena (2001: 75-6). Descartes' argument is worth stating because of its intuitive plausibility: he noted that in order to change the direction of a tennis ball I need change only the angle of my racquet; to change the ball's speed I must exert a force. Nevertheless, Newton showed that unifying change of speed and change of direction in a single concept is an important step to an empirically more adequate account of the physical world.

The introduction of SR required further conceptual innovations; such innovations can also be recounted in other scientific fields. In case after case the introduction of new concepts that are appropriate for describing some aspect of nature has been a central part of the quest for truth. This is one of the main reasons why scientists now face problems that could not even be formulated in the past. It should not be surprising to find that our ancestors did not possess the concepts needed to describe aspects of the world whose existence they did not suspect. But we have also seen examples in which new ways of thinking about familiar phenomena arose as science developed. In both of these situations it often requires a considerable body of trial and error before we can formulate a true account of our subject.

This process of developing theories, using them as a basis for research, and replacing them when they fail, is vital for achieving true beliefs in many domains. Through this process justified false beliefs contribute to the body of human epistemic achievements in ways that many currently available justified true beliefs cannot contribute. Including the *pursuit of truth* along with the possession of truth among our epistemic aims focuses our attention on justified false beliefs that exemplify epistemic values not shared by many justified true beliefs that have only local import and that do not lead to the discovery of new truths. As a result, some false beliefs have, on balance, greater epistemic value than some well-supported true beliefs. This result stands in stark contrast to the dominant view in epistemology where knowledge—which includes truth among its necessary conditions—is considered to be the maximally desirable epistemic state. On this common view, a belief that is both justified and true must always be epistemically preferable to one that is justified and false. But, I have argued, when we look at the process of seeking truth, we encounter situations in which a false belief has additional virtues that give it a greater net epistemic value than some true beliefs that lack those virtues.

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