Rethinking ‘Experimentation’ [1]

Hacking (1983) argues against a linguistic, representational approach to justifying our beliefs that the unobservable entities described in the sciences really exist. He favors in its stead an experimenting approach such that "engineering, not theorizing, is the best proof of scientific realism about entities" (1983: 274). In light of that perspective, *Representing and Intervening* concludes with a skepticism about the existence of black holes (p. 275), a position he expanded six years later in "Extragalactic Reality: The Case of Gravitational Lensing." Hacking’s astrophysical skepticism, particularly as expressed in his writing on gravitational lenses, has generated a smattering of responses that center primarily on his defense of realism (Morrison 1990, Shapere 1993, Reiner and Pierson 1995). But although Hacking tightly connects the topics of experimentation and realism, this paper will not properly address the latter.

I instead investigate Hacking’s views on experimentation. Experimentation for Hacking serves as a demarcation criterion between the natural and non−natural sciences, and as a justificatory means for substantiating claims that the unobservable entities studied by a natural science really exist. I challenge his notion of experiment’s success in either role, and offer in its place a different conception of experimentation. My view emphasizes different features than Hacking does, but does not destroy his basic – and sensible – idea: that interacting with an entity (or at least its causal powers) plays an important part in the comfort level scientists have with the idea that the entities they discuss but cannot put their hands on exist.

Experimentation and the natural sciences

After the scientific revolution of the 17th century, experimenting upon and manipulating the natural world became constitutive of scientific knowledge to a degree unprecedented before in science (Hacking 1983: 149). It was no longer considered adequate to acquire book learning and passive observation. Knowledge of nature’s secrets instead was found to rely upon experimentation: a controlled, invasive interaction with the world taken for bringing interesting phenomena into the light of day. Over time, the experimental aspect of scientific research has come to live, so to speak, according to its own rules.

A history and philosophy of science that predominately tracks theoretical activity and development in the sciences, then, suffers from two difficulties. First, such a perspective misunderstands – and even blinds a person to – the experimental side of science (1983: 261, 248). Second, an emphasis upon theory as an epistemic tool connects via correspondence representational entities (like beliefs, theories, or models) and objects in the world, a connection which has stubbornly resisted satisfactory explication since at least the time of Descartes. Hacking’s heavier weighting of experimental activity is proposed to skirt those difficulties: his view allows for a more balanced treatment of a wider range of scientific activities. His view also serves as a better stabilizer between belief in the unobservable entities described by science and things in the world.

Although this paper steers away from the topic of realism, Hacking’s arguments for experimentation connect with his brand of realism and it is difficult to extract one topic away from the other. In a nutshell, the connection between realism and experimentation is this:

1My understanding of the issues in this paper have been greatly enhanced by feedback from the science and engineering staff at the National Radio Astronomy Observatory (NRAO) in Green Bank, WV. In particular, I thank Göran Sandell for being an inexhaustible source of assistance.

You have good (or, the best) grounds for believing in the existence of a type of entity X if and only if you understand the causal powers of particular Xs well enough to experiment with them.

This is a strong thesis, but it is necessary for generating the conclusions at which Hacking arrives. Via modus tollens, because astronomers and astrophysicists do not (and cannot) experiment on the objects they study, there is no good reason to be a realist about such objects, particularly the unobservable ones. Via modus ponens, because natural scientists do experiment with the unobservable objects they study, they have good reason to be realists about those objects. The ‘if and only if’ is needed to support both inferences. This nutshell presentation of Hacking’s view paves the way for the two main questions of this paper. First, is it the case that astronomy and astrophysics are not natural sciences? Second, however one categorizes astronomy and astrophysics, is it the case that researchers in these fields do not experiment?

Hacking on Astronomy and the Natural Sciences

Does Hacking really think that astronomers are not natural scientists? His affirmative answer to that question is made almost in passing at the end of *Representing and Intervening*, where he notes his antirealism about extragalactic unobservables like black holes because knowledge of black holes is purely theoretical, not experimental (1983: 274−5). This stance is elaborated later, where with exceptions for the moon and some planets, he writes that "galactic experimentation is science fiction, while extragalactic experimentation is a bad joke" (1989: 559). Furthermore,

> The technology of astronomy and astrophysics has changed radically since ancient times, but its method remains exactly the same. Observe the heavenly bodies. Construct models of the (macro)cosmos. Try to bring observations and models into line. In contrast: the methods of the natural sciences have undergone a profound transformation, chiefly in the seventeenth century. Or one might say: the natural sciences came into being then and thereafter, while astronomy is not a natural science at all. (1989: 577)

Astronomy is in principle incapable of experimentation; all there will ever be in that field are models (1989: 576). The objects described by those models are too large and too far away ever be interfered with in an experiment. We can readily see how Hacking’s understanding of experimentation demarcates the natural from the non−natural sciences: natural sciences employ experimentation, non−natural ones do not.

But without a prior commitment to what the verb ’to experiment’ means, what ought one expect to find in the category of ’natural science’? Hacking is not exceptionally forthcoming with a protracted answer, even in a recent work which contains a section entitled "What are the Natural Sciences?" (1999: 64). In the one paragraph comprising this section, he writes that no elaboration is needed over and above the common sense intuition that the natural sciences are the old and new favorites of physics, chemistry and molecular biology. There is no bone to be picked with considering the natural sciences to be those areas of research working from the molecule down. But there is a difficulty if the sciences of very small things are the sole districts where experimentation is conceived to occur, where those and only those experimental disciplines are the best authorized to believe that the entities they research exist.

For one thing, not only astronomy but any scientific discipline whose objects of study are best pursued by means other than molecular and subatomic tampering appear to miss the perks of being a natural science, and subsequently the unobservable entities (e.g., extinct species) studied are not amenable to experimental realism. In the fortuitous event that scientists seriously consider what philosophers say about their work, a likely question they will, and do, ask is: what practical consequences does the argument endorse? On Hacking’s division of the sciences into the natural and the non, are the natural sciences somehow more worthwhile than the non−natural? Would the natural sciences deserve more funding than the others? Unfortunately there is not space enough to pursue that topic here, nor need that space be used. Experimentation need not be represented in the way Hacking does, such that while a distinction may well exist between sciences of very small things and other sciences, the difference is not obviously best settled upon experimental activity.

Elements of experimentation

Common to all the episodes of experimentation Hacking describes is a degree of control, instantiated in one of three ways. First, knowledge of an experimental entity’s causal powers serve as a control by constraining the design of experimental apparatus (262, 263, 274). Second, experimental apparatuses in turn control the causal powers of experimental entities to interfere with other parts of nature, creating a systematic effect (220−32, 237, 262, 263). Third, researchers strive to control and stabilize the causal relationship between entity and apparatus, sustaining consequent experimental effects long enough precisely measure them (233−45).

Examples of the first sort of control, let’s call it apparatus−construction control, include the device PEGGY II Hacking discusses, whose design was influenced because of the way electrons on a crystal are understood to interact with lasers. Similarly, the non−standard design of the GBT 100−meter telescope has been influenced by knowledge of how radio waves interact with radio telescope structure. Examples of the second sort of control, which we may call causal power control, are keeping electrons at a certain velocity by working with the electrons’ causal properties in an accelerator. Similarly, one can channel the radio radiation from an astronomical object through an array, or a single dish telescope. Examples of the third control, which we may call effect control, include creation of new stable phenomena such as a recorded shower of new subatomic phenomena. Similarly, stable phenomena is created when radio receiver output is recorded into printed or computerized form. But the examples of experimentation that Hacking frequents are Millikan’s determination of the minimum unit of electric charge, Cavendish’s determination of the gravitational constant, and Fizeau’s measurement of the speed of light. These measurements have significant similarities.

The first similarity is that these measurements (as opposed to other attempts) involved the use of new measurement techniques (1983: 236). This fact's significance reflects the value Hacking assigns to action over theory in justifying scientific confidence in the existence of unobservable things like the speed of light and gravity.

The second similarity is that these measurements all were measurements of physical constants (1983: 235, 243, 245). Recognizing that physical constants have high priority in his view illuminates otherwise cryptic remarks Hacking make. For example, he asserts that phenomena created by physics' experiments provide keys to unlocking the universe, while regularities detected by biologists are only anecdotal (1983: 227−28). But even if Hacking has a penchant for experiments that isolate a select few physical constants, there is no obvious need to assert that research in general counts as being experimental only if it is performed for this purpose.

The third similarity is that these measurements all occurred in the laboratory, or in laboratory conditions (1983: 237). This claim seems innocent enough until one stops to consider: what are laboratory conditions? Given the hesitation expressed above with unreflectively linking experimental conditions to the activities of physics and chemistry, I am likewise hesitant about reading laboratory conditions automatically with the conditions under which physicists and chemists work. In the spirit of the elements of experimentation enumerated earlier, I suggest that what consitututes a laboratory situation is one in which the elements of a test are taken in a controlled way without being limited to physical control. Controls are cognitive as well, such as the cognitive controls in effect in apparatus construction that stem from knowing how experimental entities work. Cognitive control is also accountability: laboratory conditions exist where – to the extent it is possible or feasible – all factors going into a test can be accounted for, from the initial conditions, to the workings of the mechanisms that process the experiment, to an interpretation of the output. One's confidence in her accountability is buttressed by manipulating experimental conditions, but because time and space force a limit on how accessible those conditions are, this confidence must come as a matter of degree.

In astronomical experimentation (if we may call it such), Hacking has his finger on an important point: there is a real issue regarding the nature of what exactly is going on at the experimental source out in space. If we evaluate that situation only in terms of having physical power over, it looks rather hopeless. But inability to exert power over initial conditions is not synonymous with being completely in the dark about them. The recognition of the range of possible initial conditions exceeding the experimenter's ability to determine or compensate for them is mirrored in a broadening of the terms in which the results are interpreted.

The limiting cases of the experimenter with her test are (1) having complete control over all conditions with only one possible interpretation of the experimental result, and (2) being ignorant of all conditions which yields an unlimited range of interpretation, or, a rather useless result. Hacking seems to draw a line shortly after the first extreme, dubbing only those activities experiments, but the reason astronomy does not cleave away so neatly away from the natural sciences is because experimentation occurs all along the continuum. Where, exactly, a discipline's experimental activity is located is not something that can be determined a priori. Therefore, while it is true that astronomers are not able to control the objects in space that they study – a fact which does add a degree of uncertainty to their findings – that situation does not uniquely force the judgment that astronomers don't experiment. Remaining is only the acceptable and obvious observation that astronomers don't experiment in the same way physicists do.

Perhaps one might retain a distinction between the empirical research performed in astronomy from the research in other natural sciences by explaining that what astronomers do is "testing," as it would be difficult to argue that astronomers do not test their claims and theories. Satisfaction with this segregation rests upon being content to reason that an experiment is what is done in proper laboratory conditions, and only physicists and chemists have proper laboratory conditions. Yet that argument is unsatisfactorily circular, for physics and chemistry are seemingly deemed natural sciences because they employ experimentation, and an answer to what an experiment is is given by pointing to what physicists and chemists do. But there does seem to be something of a difference between the two activities of testing and experimenting. I propose the following view of testing and experiment. To test is to generally challenge a technique, hypothesis, piece of equipment, idea (or what have you) against the world. Experimenting is the specific way in which a test is done.

To run this understanding on an example, a new radio telescope receiver needs to be tested every which way before it is mounted to the telescope in order that operators far away have a profile of how it works. One test is to see how it responds as it heats up from being liquid−helium cooled, so that operators and observers know what to expect in the event of a power loss. Will the receiver continue to function after it warms up, or do its parts expand such that it is effectively out of commission? After the receiver is re−cooled, will it work exactly the same as it worked before? In anticipation of such possible problems, engineers hook the receiver up to a recorder, run a test signal, and the receiver is put through several cycles of being cooled and warming up so that a stable pattern of response can be gathered. On my description, determination of the specifics of how the receiver is cooled, for how long it left to warm up, for how many trails will the test run – all these are aspects of an engineering experiment to test how the receiver responds to cooling loss.

Hacking would apparently understand the relationship between testing and experimenting differently: testing is a necessary, but not a sufficient, condition of experimentation. All experiments are tests, but not necessarily all tests are experiments, thus astronomers may be said to test but not experiment. I on the other hand advocate flipping the inferential relationship between the two activities around. An actual, performable, specified test is an experiment, but not necessarily all experiments are successful tests. This view actually fits much more readily with the observations Hacking makes about the independence of experimental activitity from high theory. Let’s look at an example of Hacking’s own, the discovery of the cosmic microwave background radiation (CMB).

Rethinking experiment, the CMB discovery

Hacking selects this discovery from the history of science because it is a prime instance of experimental work, a "sheer dedication to an experimental freak" (1983: 159). This experiment in the 1960s got its start in the 1930s with developments in radio communications, when unexpected sources of radio noise were detected. Gradually these sources were matched with known objects; Karl Jansky (the grandfather of radio astronomy) matched the steady hiss he found with its origin in galactic central. Roughly 30 years later, Arno Penzias and Robert Wilson

> adapted a radiotelescope to study this phenomenon. They expected to detect energy sources and that they did. But they were also very diligent. They found a small amount of energy which seemed to be everywhere in space, uniformly distributed. (1983: 159)

But for all they knew, the excess radiation could have originated from their telescope and receiver. In terms of temperature the excess corresponded to roughly 4 Kelvins more than what was expected. Since Penzias and Wilson couldn't account for it, they exhaustively searched for sources of instrumental error, eliminating every conceivable source of noise including those famous pigeons nesting inside the horn of the telescope. They also checked the area all known candidates for being the source of the excess energy, such as New York City 50 miles away and possible of effects from a high−altitude 1962 nuclear explosion. A year later Penzias and Wilson were left with an excess of about 3K, which they still couldn't explain. Bernard Burke made the explanatory match, linking Penzias and Wilson at Bell Labs with a group at Princeton working toward testing their prediction of a universal low−temperature (roughly 3K) radiation left over from a Big Bang that threw our universe into existence. Hacking's conclusion from this episode is that

> It is sometimes said that in astronomy we do not experiment; we can only observe. It is true that we cannot interfere very much in the distant reaches of space, but the skills employed by Penzias and Wilson were identical to those used by laboratory experimenters. (1983: 160)

After having discussed the senses of testing, experimenting, and laboratory conditions above, we can work to see why Hacking thinks the astronomers Penzias and Wilson demonstrated laboratory skills. Along the lines of experimental control discussed above, did Penzias and Wilson construct their apparatus in light of knowledge of the causal properties of the phenomenon they would up investigating? No. Did Penzias and Wilson strive to control the causal properties of the phenomenon they investigated to create an experimental effect (a chart recording of temperature) with their apparatus? No. Did Penzias and Wilson work to stabilize their experimental effect? No. While these points work well to support Hacking's claim that experimentation lives a life fairly independently of high theory, they do not bode well for being experimental, either. What laboratory skills, then, could Penzias and Wilson have demonstrated? The very skill I mentioned above: being able to account for as much as they knew was going into their test, in their exhaustive checking of every element that could contribute input. To the extent that any scientist —physicist, chemist, astrophysicist —is able to and does do this for the purpose of working out (and not just thinking out) claims, equipment or what have you, that scientist is performing an experiment.

Rethinking Experiment

This paper has explored the features of experimentation with the aim of opening those features up such that they are adjudicatable on the terms different scientific fields set for themselves, in an open critical manner as articulated by, for instance, Hull (1988) and Longino (1994). In light of that I offer the following reformulated definition of ‘experiment’:

> An activity under controlled and/or known conditions where the experimenter works with the causal powers of an entity in order to reveal (possibly by creating anew) a phenomenon stable enough to be accurately measured.

With this reformulated notion of ‘experiment’ I turn to the last example of this paper, gravitational lenses. Do astronomers test their models of gravitational lenses with experiments?

For some quick preliminaries, what a gravitation lens is, is a massive object lying in the line of sight between a source and observer. The gravitational mass of the intervening body acts as a lens in that light rays from the source bend around the lensing object and the results can vary. Sometimes the source object may appear multiply. Sometimes the image of the source object is so warped it appears as an arc or a ring around the lens. The lens itself can take several forms. It can be a galaxy. If far enough away, it can be a tight cluster of galaxies. It can be a star. It can be dark matter (perhaps small, very cold stars). Source objects, if nearby, can be stars. Distant source objects are typically quasars or quasi−stellar objects, which are extremely bright but are believed to be very distant. Hacking’s question in his article concerns whether one should be a realist about gravitational lenses.

Astronomers usually take note of quasars with certain qualities: their degree of distortion, their proximity to one another, similarities in spectral lines (indicative of their chemical constitution) and similarities in their redshifts (indicative of their distance). What seems wrong with this picture from Hacking’s position is that from the observation of a gravitational lens effect, astronomers infer (and then look for) the existence of a lensing object which is the cause. That puts the experimental process backwards because what should receive first attention is the causally responsible entity. This ordering problem is complicated by other difficulties: that the gravitational lenses are either in principle undetectable (because they are constituted of dark matter) or several candidate lenses are detectable but there is no good way to disambiguate which of the objects is actually causally responsible for the lensing (1989: 566). Furthermore, there are discrepancies between theory and what is observed, running from how many lensed images are predicted on the basis of a certain gravitational lensing system versus how many images are detected, to whether there are too few or too many lensing systems detected given what the physics would have a person expect (1989: 570−73).

All those problems being what they may, that should not distract us from what ought to be the main point, which is: where, exactly, is there a problem with the experiment? Excepting the possible, but ungiven and unacceptable (for reasons the first half of this paper has already covered) response that astronomers are not doing experiments with gravitational lenses because they are not conducting their research within the controlled conditions of a lab, this issue is not really addressed. Another potential problem might be that we don’t have on−hand a stockpile of gravitational lensing systems to manipulate systematically for creating an experimental effect. That is no surprise, but the problem as it is presented in astronomy is more a cry for more data than for a lost cause. Let’s look at steps that are being taken to remedy the situation by examining a new type of gravitational lens investigation – the detection and exploration of binary lensing systems. This began with OGLE (Optical Gravitational Lensing Experiment) No. 7.

Polish and American institutions and researchers have collaborated to create OGLE, which is "a long−term observing project with the main goal of searching for dark matter in our Galaxy using microlensing" (Udalski et al. 1994, L103). What they have been doing is surveying dense stellar fields toward both the galactic bulge and the Small and Large Magellanic Clouds for signs of microlensing due massive but unobservable bodies, most likely small cold stars. The first phase of the project began in 1992, using the 1−meter Swope telescope at the Las Campanas Observatory in Chile. Limited observing time but promising results led to the second stage, the construction of a 1−meter class telescope that would be dedicated to photometric surveys of stellar fields. In 1997 the Polish telescope was commissioned and the second phase of the project has been since ongoing.

One of the promising results found in OGLE's first phase was the first proposed detection of a binary lensing system. With microlensing generally speaking, the light curve from the source object is a non−repeating dramatic increase in brightness (due to the foreground passing of the lensing object) which quickly tapers back to its original intensity level. What alerted OGLE observers that the No. 7 observation light curve harbored something different was that after the peak, the light curve bottomed at an intensity higher than normal and then began to increase again. That there could be binary lensing objects, especially if they are small cold stars, is not surprising; at least half the stars in the Milky Way occur in pairs. But such a detection in this case wasn't expected, and the finding was quite exciting because the observed light curve closely matched the light curve theoretically predicted in 1991 to result from a binary lensing system (Udalski et al 1994: L103). The tentative nature of the finding is expressed in the 1994 title and text, "Binary Microlens or a New Unusual Variable?". That is to say, stars (such as Cepheid variables) exist whose intensity varies in systematic ways, and there are several different pattern types of variable stars. And, actually, quite a few things vary in intensity in the Universe. Though the observed light curve of OGLE No. 7 didn't match any of known signature variations it is possible that they found a new variable star rather than the gravitational lensing of a distant star by a binary lens.

Of course astronomers would like to go out and check directly for what's happening out in space. But since that's not possible, the only thing to do is wait and see if the fluctuation in brightness repeats. Because chances that microlensing the same star is quite low, if the fluctuation repeats then the brightness variation is probably intrinsic. Coupled with a better catalog of the varieties of varying phenomena there are in the universe, empirical investigations of the objects in the universe can be better limited or controlled, such that the beliefs in the existence of gravitation lenses which may under repeated testing turn out to be wrong. But "wrong" is not the judgment to date.

Besides the OGLE group there are other teams that have organized for the purpose of studying microlensing phenomena. In particular, the Australian−American team MACHO (MAssive Compact Halo Objects) and the worldwide PLANET (Probing Lensing Anomalies NETwork) organization,[2] besides researching unto themselves, broadcast publicly (on their websites[3] and directly by email to enlisted participants) alerts and warnings of apparent binary lensing occurrences. This is done in order that other interested observers can collect data, which can either corroborate or challenge their own findings. This is not an uncommon feature of empirical astronomy. What researchers lack in controlling initial conditions they perhaps make up in terms of pooled techniques and data both within and across subdisciplines.[4] Favorable results typically retain a degree of interpretative caution, indicative of initial uncertainties, which might spell disaster in a philosopher's mind. But a good detection – as tinged as it is with the uncertainty that seems inescapable in this field – is as hard to find in astronomy as steady measurable phenomena are as difficult to create in the physicists lab. That these observations are taken with equipment designed to work with the causal properties of unobservable entities, that the causal powers of the entities are controlled by these devices in such a way as to create a stable effect are indicative that to the extent that astronomers are able, these works on graviational lensing are experiments.

Concluding remarks

Hacking argues that scientific knowledge comes not only from books and observation; one also must "twist the lion's tail" (1983: 149). Yet in terms of size, we humans stand midway between an electron and the cosmos, separated on both sides by a magnitude of 10^{30} (Kraus 1966: 32). If humans are linked to the entities at either end of this size spectrum by a tenuous chain of causal relations from which we infer the existence of unobservable entities, then it seems Hacking's best reason for having more confidence in entities on the low end of the spectrum than in entities on the high side is because our presence towers over the little things. I am doubtful as to whether that reason is a satisfactory basis for a scientific realism.

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2 Other groups working on lensing phenomena are the French team EROS (Experience pour la Recherche e'Objets Sombres), the French−English team AGAPE (Andromeda Galaxy and Amplified Pixels Experiment).
3[3] http://wwwmacho.mcmaster.ca/, http://www.astro.rug.nl/~planet/
4 A striking example which is worth the writing of another paper is the collaboration of optical, gamma−ray and radio astronomers in honing down the source of gamma−ray bursters.

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