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The Theory-Ladenness of Observation and the Theory-Ladenness of the Rest of the Scientific Process

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We use evidence from cognitive psychology and the history of science to examine the issue of the theory-ladenness of perceptual observation. This evidence shows that perception is theory-laden, but that it is only strongly theory-laden when the perceptual evidence is ambiguous or degraded, or when it requires a difficult perceptual judgment. We argue that debates about the theory-ladenness issue have focused too narrowly on the issue of perceptual experience, and that a full account of the scientific process requires an examination of theory-ladenness in attention, perception, data interpretation, data production, memory, and scientific communication. We conclude that the evidence for theory-ladenness does not lead to a relativist account of scientific knowledge.

1. Introduction. One of the recurrent issues in the philosophy of science has been the analysis of the possibility that scientific theory influences scientific observation. Hanson (1958) and Kuhn (1962) made very influential arguments that theory does influence observation. More recently Churchland (1979, 1988) and Fodor (1984, 1988) have taken up the issue. Churchland argued for a very strong form of theory-ladenness, while Fodor argued that visual perception is modular and that higher-level theoretical beliefs do not penetrate the perceptual module.

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All of these discussions have taken a naturalized approach to the theory-ladenness issue. The earlier work of Hanson and Kuhn relied strongly on empirical work from Gestalt psychology and from the "New Look" in perception (e.g., Bruner and Postman 1949). The debate between Churchland and Fodor has used more recent work in cognitive psychology and neuroscience. One goal of the present paper is to evaluate the state of play on these issues in current cognitive psychology.

However, in examining these issues from the point of view of the psychology of science, we have come to believe that the debate has focused much too strongly on the issue of (visual) perception. Given the long tradition in philosophy of emphasizing the role of visual experience in determining beliefs, it is clear why this area has been the battleground. However, it seems to us that if our goal is to understand the process of science, then we need to take a much broader view of the work of the scientist and not just focus on the issue of the visual perception of scientific phenomena. Therefore, in this paper we will examine the issue of the influence of theory on the following aspects of the scientific process: (a) perception, (b) attention, (c) data interpretation, (d) data production, (e) memory, and (f) scientific communication.

In current cognitive psychology there is much debate about the exact nature of the representation of molar forms of knowledge. Recent examples include schemata (Brewer and Nakamura 1984), mental models (Johnson-Laird 1983), naive theories (Gopnik and Wellman 1992), and perceptual symbols (Barsalou 1999); see Rumelhart and Norman 1988 and Brewer 1999 for reviews. For the purposes of this paper, we will use the term 'theory' to refer to all higher level forms of knowledge. This usage will then be consistent with the literature on theory-ladenness in philosophy, which also tends to use the term 'theory' in this very broad sense.

In the paper we will examine the theory-laden issue for each of the aspects of the scientific process listed above. Within each process we will first analyze the relevant literature from cognitive psychology and then we will provide some relevant cases from the history of science; see Brewer and Lambert 1993 for an earlier attempt to analyze these issues in a cognitive science framework. Since there is little experimental evidence available using scientists as participants, most of the findings described in this paper will be from nonscientists. However, we assume that the underlying cognitive processes of scientists are similar to those of nonscientists (cf. Brewer, Chinn, and Samarapungavan 2000).

2. Perception. In the philosophy literature discussing the theory-laden issue, the terms 'see' and 'perceive' have often been used very broadly to cover a number of aspects of the scientific process (e.g., Kuhn 1962). In this section we will try to restrict our analysis to clear cases of perception used in the narrower sense of conscious (visual) experience. In analyzing the literature on the theory-ladenness of perception we adopt the modal view in current cognitive psychology that perception is determined by the interaction of top-down theory information and bottom-up sensory information (cf. Lindsay and Norman 1977; McClelland and Rumelhart 1981). Pylyshyn (1999) has recently written a provocative piece arguing that the early stages of the perceptual process are encapsulated from cognition. His arguments are directed at a detailed analysis of the early stages of perception and do not, for the most part, affect the approach taken here. Even though his paper is designed to limit the role of theory in certain aspects of the perceptual process, he notes that "vision as a whole *is* cognitively penetrable" (1999, 344).

Much of the debate between Churchland (1979, 1988) and Fodor (1984, 1988) involves visual illusions such as the Müller-Lyre illusion. Fodor concedes that illusions such as this may involve some low-level theory operating within the perceptual module, but points out that this is not the type of higher level theory that has interested friends of theory-ladenness in the philosophy of science. On this we think he is correct. Then, he points out that perceptual illusions of this type are actually strongly resistant to information from higher-level theory. In particular, he notes that even after one has measured the lines in the Müller-Lyre figure and found them to be the same length, they continue to be perceived as differing in length—thus, whatever is causing the illusion is not very cognitively penetrable. It seems to us that the data are with Fodor on this issue and he wins the battle.

However, we want to argue that Fodor loses the war. We think there are a number of studies that show that theory can influence perception. Leeper (1935) carried out a series of experiments showing that previous exposure to an unambiguous picture of either an old woman or a young woman has dramatic effects on the perception of an ambiguous figure. Almost all of the participants in the experiment who had seen the unambiguous young woman perceived the ambiguous picture as a picture of a young woman, and almost all of those who had seen the unambiguous old woman perceived the ambiguous picture as an old woman. These are not simply "interpretations" of an ambiguous stimulus—the old woman/young woman picture (Boring 1930) is a classic example of a figure that gives rise to two qualitatively different perceptual experiences. Note the relation of this experiment to cases in science where a scientist has seen several instances of some class of objects and now has a new object that has to be classified. However, one might argue that episodic perceptual priming of this sort is not really an example of a true abstract theory operating on perception. In that case consider the experiments of Bugelski and Alampay (1961) using the rat/man ambiguous figure. They found that showing the participants a series of pictures from a conceptual class (e.g., animals) that did not include the crucial instance (the rat) was enough to cause dramatic shifts in how the participants perceived the ambiguous figure.

Gunstone and White (1981) carried out an experiment that is an even closer parallel to past cases in science. These experimenters showed first year college students two balls falling (one iron and one plastic). They then asked the students to record their observations of the results of the experiment. They found that those students whose initial hypothesis was that a heavier metal ball would fall faster than a lighter plastic ball were more likely to report observations supporting their theory than were students whose initial hypothesis was that the two balls would fall at equal speeds.

It seems to us that these experiments show that the theory-laden view is correct—there are cases where theory influences perception. This conclusion is thus at odds with Fodor's (1984) view that visual perception is an encapsulated module not penetrable by theory. However, note that in all of the above cases the stimuli were either ambiguous, degraded, or required a difficult perceptual judgment. In these cases the weak bottom-up information allowed the top-down influences to have a strong impact on perceptual experience. It seems likely that strong bottom-up information will override top-down information. If the information to be perceived is whether a needle on an instrument is registering a 10 on a clear 1–10 scale, it is unlikely the theoretical beliefs of the scientist will be able to override the strong bottom-up perceptual information. Thus, the top-down/bottom-up analysis allows one to have cases of theory-laden perception, but does not necessarily lead down the slippery slope to relativism (e.g., Barnes 1974; Woolgar 1988).

We will now shift to evidence from the history of science. The history of astronomy is a good source for examples of theory-laden observations. Observational astronomers are constantly pushing their instruments to the edge of technology and thus are often making observations with very weak bottom-up information. One of the first important observations Galileo made with his telescope was that there are a number of moons orbiting Jupiter. Accordingly, when he made his first observations of Saturn he drew it as a large planet with a moon on each side of it. Van Helden (1974) has gathered together many of the early observations of Saturn. His work shows that for the next 50 years, when astronomers drew what they saw in their telescopes while observing Saturn, they typically drew it with moons and/or handles coming out of the poles; none drew it as a planet with rings. It appears that their belief that some planets had moons distorted their perceptions of Saturn's rings.

The N-ray affair in physics provides another example of the role of top-down theory in perception. Soon after the discovery of X-rays, experimental physicists began searching for other new forms of radiation. In 1903 Blondlot, a distinguished French physicist, announced the discovery of a new form of radiation that he called N-rays (Klotz 1980; Nye 1980). The techniques Blondlot developed to detect N-rays required relatively subtle perceptual discriminations. For example, one form of detector required the observer to judge the increase in activity in a spark gap. Soon over 300 papers by 100 different scientists were published on the properties of N-rays. The literature on N-rays came to a rather rapid end when Wood, an American physicist, published a paper describing a visit to Blondlot's lab in which he discovered that Blondlot's observers were still able to detect N-rays after he had disturbed the apparatus so that no N-rays should have been available.

These examples from the history of science appear to show that perception is theory-laden. Such cases parallel those from the cognitive psychology literature, in that the phenomena to be observed were ambiguous, degraded, or required a difficult perceptual judgment. If Blondlot had developed a meter that gave a clear reading when exposed to N-rays (i.e., clear bottom-up information), it seems quite unlikely that this episode in the history of physics would have occurred.

3. Attention. Another important way that theories can impact the scientific process is through attention. Neisser and Becklen (1975) carried out a study in which participants viewed two superimposed visual events (a hand game and a basketball game). When asked to attend to one of the events, participants could report it accurately, but they reported that the nonattended event tended to fade from consciousness and they could recall little from it. This study clearly shows that attention is under cognitive control, but it is not clear if the effect is due to rapid forgetting of the nonattended event or to an actual lack of perception. A recent study by Rees et al. (1999), using letters and pictures and measuring brain activity with fMRI, suggests that the nonattended event is not perceived by the higher cortical centers.

Astronomy offers us many interesting cases of the operation of theory-directed attention. One important class of cases are known in astronomy as "pre-discovery" observations. After some astronomical object is "officially" discovered, astronomers often make a theory-directed search through their previous observations to obtain additional data. For example, Forbes (1983) found evidence for 22 pre-discovery observations of Uranus. In these cases observations were sometimes rejected on methodological grounds, sometimes they were reinterpreted, and sometimes they were ignored (cf. Brewer and Chinn 1994a).

A carefully reported example of theory-directed attention processes occurred with the discovery of Pluto's moon Charon (Harrington and Harrington 1979). In 1978, when examining a photograph of Pluto, James Christy noticed similar fuzzy regions on pictures taken within a week of each other. He then looked at a picture taken a month later and noted the different location of the fuzzy region. He next dug out all of the older pictures of Pluto he could find (many of which he had previously examined carefully in order to make calculations of Pluto's orbit). Paying attention to the systematic movement of the fuzzy region, he was eventually able to provide a precise calculation of Charon's orbit around Pluto.

Overall, it appears that the above evidence from cognitive psychology and the history of science provides good support for the thesis that attention is theory-laden. However, as in the case of perception, there are bottom-up constraints on the attention processes. When the bottom-up processes are strong (e.g., a large salient object moves into your field of view) you see it even if it is unexpected. Thus when Tycho Brahe looked up into the night sky in 1572 he saw a new star (a supernova), even though his past experience and Aristotelian theory both led to the expectation that no new star should be there.

4. Data Evaluation and Interpretation. Bogen and Woodward (1988) and Fodor (1991) have made strong arguments that empirical information in modern science is frequently not perceptual observation, but more abstracted and reduced observations that we will call data. Brewer and Chinn (1994a) analyzed the responses scientists make when they obtain data that is in conflict with their theories. Brewer and Chinn concluded that scientists in this circumstance adopt a variety of strategies that avoid the need to change theories; for example, scientists ignore data, reject data, exclude data, hold data in abeyance, and reinterpret data. All of these can be thought of as theory-laden ways of treating data.

In cognitive psychology there have been a large number of studies showing that providing a theory for data can lead to much greater comprehension and memory for stimulus material. For example, Bransford and Johnson (1973) studied apparently anomalous sentences (e.g., "The haystack was important because the cloth ripped."). They found that comprehension and memory were greatly improved when the participants were provided with an appropriate theoretical framework (e.g., a parachute). Other studies have shown comprehension and memory effects that are produced when different individuals provide different interpretations of the same stimulus material. For example, Anderson et al. (1977) showed that undergraduate music majors tended to interpret an ambiguous passage as being about a music rehearsal, while nonmusic majors interpreted it as being about a card game.

Brewer and Chinn (1994b) carried out a study on the theory-laden evaluation of data that is more directly analogous to the situation in the process of science. They had one group of participants read passages supporting theory A (dinosaurs were warm blooded) and another group read passages supporting theory B (dinosaurs were cold blooded). Each group was then asked to evaluate data that were either consistent or inconsistent with the theory they had read earlier. The same piece of data was considered more believable when it was consistent with the participant's theory than when it was inconsistent.

The role of theory in data that were previously not understood is such an obvious feature in the history of science that it does not require documentation. Examples of data reinterpretation, such as the Copernican revolution, are also quite visible in the history of science. Gould (1981) has provided a well-documented account of how theoretical beliefs about race and skull size led to systematic errors due to data rejection, exclusion, and reinterpretation. He points out that the errors are unlikely to have been due to conscious theoretical bias, since the scientists frequently published enough of the raw data that Gould was able to trace the path of data manipulation and refinement.

Paleontologists are in the interesting situation of having some of their theory-laden interpretations of data on public display. Shipman (1986) has shown how public models of the Iguanodon have evolved. The first reconstruction showed similarities to living iguanas. Later, the Crystal Palace reconstruction showed similarities to a rhinoceros. Next, the reconstruction in the Royal Museum of Natural History in Brussels showed similarities to a kangaroo. They are currently thought to have been fast moving predators with a rigid tail.

It seems to us that top-down processes have a very strong role in data interpretation (and thus provide the strongest arena for the relativist). However, we believe, once again, that there are typically strong bottom-up constraints. Note that in the work of Anderson et al. (1977) the experimenters had to work hard to provide a text that allowed two clearly different interpretations, and once they had done that, there were strong constraints in the text that ruled out most other interpretations; for example, we can be fairly sure that no participant in their experiment interpreted the text as being a description of the nuclear processes in the supernova that formed Tycho's new star. The paleontology example makes the point nicely. When only a few bone fragments were known, it was possible to interpret the creature as something like an iguana. But now, with much more complete skeletons available, that interpretation is ruled out.

5. Data Production. In cognitive psychology, Klahr and Dunbar (1988) have attempted to study aspects of the scientific data production process using a problem-solving task that had participants program an electronic device. The participants were asked to carry out "experiments" to discover how a particular function worked. They discovered that some participants took a theory-based approach to the design of experiments while other participants took a more low-level data oriented approach. In the particular task they were studying, the theory-based approach was more successful.

One might think that the measuring of the non-theoretically derived physical constants would be the stronghold of non-theory-laden Baconian empiricism. However, it appears that there is much theory embedded in the experimental apparatus and in the way the experiments are carried out. The physicists have committees whose job is to establish the "official" figures for various particle parameters and physical constants. These groups have plotted the change in the measurements of the constants over time and have noted that they tend to cluster together for a period of time; then one measurement may be many standard deviations away from the previous measurements; and later a new cluster develops. The physicists even have a term for this effect: "intellectual phase locking" (Cohen and DuMond 1965; Franklin 1986). They argue that the effect is due to the influence of the currently established value on the way the later experiments are carried out, and they joke that the experimenters fight the systematics until they get the "right" answer (i.e., an answer that roughly agrees with previous experiments).

6. Memory. The psychological process of memory has rarely been considered in philosophical discussions of the theory-laden issue, yet it seems likely that it plays an important role in science. Beginning with the early work of Bartlett (cf. Brewer 2000), researchers in cognitive psychology have argued that human memory is strongly influenced by beliefs, that information related to an individual's theory will be easier to recall, and that information that deviates moderately from an individual's theory will tend to be distorted in recall in the direction of the theory.

Vicente and Brewer (1993) examine a number of historical cases of consistent distortions of experimental findings in the published literature (e.g., that Galileo carried out experiments with falling objects from the Tower of Pisa) and argue that many of these are probably cases of theory-based memory errors. They support their argument with a memory experiment that used a correct account of an experiment that has shown consistent distortions in the secondary literature. Participants who read this text made errors in recall that reproduced many of the errors found in the published accounts.

Thus it appears that theory-laden memory effects could be playing an important background role in the scientific process. When scientists disagree about the evidence it may be that each is relying on a somewhat differently recalled set of evidence. However, once again, there are constraints on the influences of the top-down processes on memory. Memory for most ordinary life events appears to be fairly accurate (Brewer 1988). Note that the institutions of science also include processes designed to reduce memory error (e.g., keeping timely lab notebooks).

7. Communication. A final place to look for theory-ladenness is in the process of communication among members of the scientific community. Within cognitive psychology van Dijk and Kintsch (1978) have provided an account of the summarization process in terms of a set of macrostructures which serve to reduce and organize the information in a text. These rules involve such things as the deletion of nonthematically related information and so are clearly theory-laden.

Anyone who has read a literature review by a strongly theory-driven scientist knows the strong role that theory plays in what scientists choose to communicate. Gooding (1992) recently provided a general account of how information known to a scientist is selected for inclusion in scientific publications. Holton (1978) provided a detailed analysis of Millikan's research on measuring the charge of the electron. He showed that over half of the observations that were in the laboratory notebooks were not included in the final published paper, even though Millikan states in the paper that it includes all of the obtained data.

Discussing the communication process raises an important issue about the mental processes we have analyzed. In all of the earlier cases we assume that the top-down processes operate outside of conscious awareness (in fact, if a scientist consciously and deliberately distorted data, they would be open to a charge of scientific fraud). However, in the case of communication it is likely that some of the theory-laden processes are conscious and deliberate decisions by the scientist designed to influence their readers. The scientific community helps reduce the degree of theory-ladenness in scientific communication through the publication review process.

8. Conclusion. This analysis suggests that theories do influence perception and thus supports this aspect of the original claims of Hanson and Kuhn. However, the top-down/bottom-up approach taken in this paper also reduces the bite of this claim, since it assumes that when bottom-up evidence is strong, it is not easily overridden by top-down information. It seems to us that this intermediate position gives a good account of the evidence from cognitive psychology and the history of science.

The other major conclusion from this analysis is that the theory-laden issue has been too narrowly focused on the theory-ladenness of perception. If one wants to understand the full scientific process one needs to adopt a much richer account of the cognitive processes that are involved in carrying out science. The account given in this paper suggests that theories may have their greatest impact not in observation, but in other cognitive processes, such as data gathering, interpretation, and evaluation.

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