The Theory-Ladenness of Observation: Evidence from Cognitive Psychology

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Abstract

In this paper we examine the theoretical and empirical work in psychology that is relevant to Hanson's (1958) and Kuhn's (1962) arguments for the theory-ladenness of observation. We conclude that the data support the Hanson and Kuhn position against the earlier positivist views that sensory data provides an completely objective basis for deciding between rival scientific theories. However, the data also suggest that top-down influences on perception are only strong when the incoming sensory input is weak or ambiguous. Thus, in cases where the bottom-up sensory evidence is strong and unambiguous, there is little evidence that theory can override observation, and so the data do not support the strong form of the theory-laden position that is sometimes attributed to Hanson and Kuhn. In addition we argue that philosophical work on theory-ladenness has focused too narrowly on the issue of perception and ignored attention and memory. Our analysis suggests the need for a much broader view of the mental processes involved in doing science, and our synthesis of the empirical literature shows the influence of top-down schemata on perception, attention, comprehension, and memory. This top-down, bottom-up synthesis seems to us to provide a satisfying resolution of the controversy over the theory-ladenness of perception.

Introduction

In 1958 in *Patterns of Discovery* and in 1962 in the *Structure of Scientific Revolutions* Norwood Hanson and Thomas Kuhn made very influential arguments for the theory-laden nature of observations. These works attacked the view of the logical empiricists that observation provides a theory-neutral window on the world (Suppe, 1977). The logical empiricists had argued that scientists could always appeal to neutral observational data as the final arbiter of theoretical disputes. In the philosophy of science the issue of the theory-ladenness of observations has been highly controversial, and the debate continues to the present time (Churchland, 1988; Fodor, 1984, 1988; Gilman, 1990; Kordig, 1971; Lane & Lane, 1981; Werth, 1980).

Hanson and Kuhn based some of their arguments on an analysis of a number of psychological experiments. It has now been more than 30 years since this work was published and cognitive psychology has flourished during that period. In the present paper we propose to examine the theoretical and empirical work in psychology that is relevant to Hanson's and Kuhn's arguments and work out the implications of our analysis for the larger theoretical issues in the philosophy of science.

In this paper we will use the term "schema" (Brewer & Nakamura, 1984; Rumelhart, 1980) broadly to refer to the cognitive structures in long-term memory that underlie many aspects of human cognitive functioning. For the purposes of this paper the term *schema* as used by psychologists can be taken to be roughly equivalent to the term *theory* as used by philosophers of science.

Our analysis of the philosophical literature on the theory-ladenness of observation suggests that most of scholars in this area have implicitly adopted a relatively limited conception of the mental processes involved in carrying out science and have focused on the role of schemata in visual perception. In order to provide a more precise account of the role of schemata in science we think it is necessary to distinguish a number of basic mental processes that play a role in scientific thinking and examine the evidence for top-down schema effects in each of these domains. In particular, we propose to study the role of schema in: perception, attention, comprehension, and memory.

Within each of these mental processes we will first examine the experimental literature from cognitive psychology, then discuss some selected cases from the history of science, and finally sketch out the theoretical implications for the philosophy of science.

Schemata in Perception

Much of the discussion of the problem of theory and observation in the philosophy of science has used the terms "observation" and "perception" in a very broad way that includes interpretation and a number of other mental processes. In this section we plan to limit our discussion to the issue of the role of schemata in sensory perception. In particular we want to examine the laboratory evidence supporting the position that schemata can literally change what one perceives in the world.

Evidence from Psychology

Reversible figures. A number of philosophers of science have used evidence from visual reversible figures (e.g., the Necker cube) as support for the theory-laden nature of observation. We agree that these visual illusions show that the same visual input can give rise to different phenomenal experiences, but we do not think there is convincing evidence that the changes in perception are produced by schema processes. In fact, the relatively involuntary nature of the perceptual reversals suggest the operation of visual processes at some lower level of the visual processing system.

Ambiguous pictures. Is there laboratory data that schemata can literally change the perception of the world? We think there is clear evidence on this topic from studies of the influence of prior knowledge on the perception of ambiguous figures. Leeper (1935) has shown that previous exposure to an unambiguous picture (old woman or young woman) produces dramatic differences in the perception of an ambiguous figure (old woman/young woman, Boring, 1930). The subjects give schema-consistent responses (i.e., those that had previously seen the unambiguous old woman report seeing an old woman when viewing the ambiguous figure, and vice versa). Bugelski and Alampay (1961) have shown that providing subjects with information about the conceptual category of the picture (e.g., animal or human) shifts the percentage of subjects who see either a man or a rat in an ambiguous figure. These experiments appear to be particularly clear cases of the impact of schemata on perception since, with these pictures, the experience is not one of conceptual interpretation, but rather of having one qualitative perceptual experience or another.

Top-down and bottom-up processes. There is an important consensus in current cognitive psychology that perception is the result of the confluence of top-down schema-based information and bottom-up sensory information (cf. Lindsay & Norman, 1977, p. 251; McClelland & Rumelhart, 1981). All of the experiments discussed above are examples of top-down influences on perception. However, note an interesting feature of these experiments. In every case the stimulus input was either ambiguous or degraded. If there is a clear unambiguous stimulus it will override schema-based information. Thus, if someone shows you a ball point pen and tells you it is really a platypus, it still looks like a ball point pen. Of course, it is possible for the schema-based processes to modify the *interpretation* (comprehension) of any given perceptual input. Thus, the physicists have convinced many of us that the solid objects around us are mostly empty space, but we still perceive them as solid objects.

Overall, we conclude that the evidence from cognitive psychology supports the position that schemata can influence perception (i.e., observations are theory laden), but that this occurs only for ambiguous and degraded sensory input.

Evidence from the History of Science

In the philosophy of science literature there are a large number of historical cases that have been taken as evidence to support the theory ladenness of observation. We think that most of those examples do show the operation of schemata on psychological processes such as attention or interpretation, but find only a subset of examples that seem clear cases of schemata operating on perception.

Early astronomy. The early history of astronomical observations by telescope provides many good cases. In 1610 Galileo first turned his telescope on Saturn and drew what he observed as a large sphere with two smaller spheres on either side of it. For the next fifty years astronomers continued to publish drawings of Saturn, most of which show it with smaller satellites or with handles coming out of the north and south poles (Van Helden, 1974a). Finally in 1655 Huygens apparently had the theoretical insight that Saturn might be surrounded by a thin ring. Within a few years after Huygens published his theory most astronomers came to see Saturn with a ring. In fact, one astronomer, who was still trying to defend his satellite model several years after Huygens announced the ring model, admitted that he now had trouble not seeing a ring when he was actually observing Saturn (Van Helden, 1974b, p. 165). Thus, in this one historical episode we have evidence that the astronomers' preexisting schemata (e.g., that planets had satellites) made it hard for them to see the rings, and then soon after Huygens's "discovery" the new schema facilitated the perception of the rings.

Another case from early astronomy involves the English astronomer's Harriot's early drawings of the moon. His initial drawings of the moon show a confused jumble of lines; however, after seeing a copy of Galileo's *Sidereus nuncius* with pictures of the moon's craters, Harriot's next drawings of his observations of the moon also show craters (Bloom, 1978).

N rays. Another interesting case comes from physics at the turn of the century. Soon after the discovery of X rays a French physicist, Rene Blondlot, announced the discovery of N rays. Blondlot claimed that N rays were a new form of electromagnetic waves that could be detected by slight increases in the brightness of a spark arcing across a gap (Nye, 1980). Almost 300 papers were published by about 100 different scientists working out the properties of N rays before a very critical paper (Wood, 1904) by an American physicist brought the research to a halt. Wood made a visit to Blondlot's lab and reported that Blondlot and his assistant could still observe N rays even when the apparatus had been adjusted so that no N rays could have been emitted.

It seems to us that these cases from the history of science are examples of schema processes operating to influence perception. Note that in all of these cases the information to be observed is degraded or at the very limits of of detectability, just as would be expected from the experimental work in cognitive psychology. If the early astronomers had been given a Voyager 2 photograph of Saturn, they would have seen a ring and not satellites or handles.

Schemata in Attention

Another psychological process that can be influenced by schema-based processes is attention.

Evidence from Psychology

Schema-directed attention. There is a large experimental literature showing that subjects can direct attentional resources to schema-relevant aspects of a perceptual array (cf. Johnston & Dark, 1986). For example, Neisser and Becklen (1975) have shown that if people view overlapping films of two different events (e.g., a basketball game and a hand game) on the same screen, they can focus attention on one of the two events and respond to the schema-relevant events almost as well as if the other event was not present. When attention is focused on the one event there is little awareness of information from the other event. Thus, if there is some schema-based reason for paying attention to a particular aspect of the world, it would appear that people can direct their attention to these schema-relevant aspects.

Schema-inconsistent attention. There is also a literature showing that schema-inconsistent information attracts attention. Several studies (Friedman, 1979; Loftus & Mackworth, 1978) of the eye movements of individuals looking at pictures suggest that schema-inconsistent objects (e.g., an octopus in a barnyard scene) are given more attention (longer fixations) than are schema-consistent objects (a cow in a barnyard scene).

Thus, overall there seems to be good evidence that schema-based processes can direct attention toward schema-relevant information and that schemata can form a background in which schema-inconsistent information attracts attention.

Evidence from the History of Science

Schema-directed attention. There are a large number of cases in the history of science where theory leads an investigator to pay attention to something that would not otherwise be noticed. For example it is known (Hetherington, 1988) that many astronomers had photographed Neptune before it was officially discovered. However, it was only after theory-based calculations had suggested the location of an unknown planet that Johann Galle carefully examined the appropriate region of the sky and made the discovery.

Schema-inconsistent attention. Kuhn (1962, ch. 6) has pointed out the important role that a well-developed theory plays in directing attention to data that is inconsistent with the theory. Thus, it was only within the context of the well-developed theory of Newtonian mechanics that scientists were able to notice the small inconsistencies in the orbit of Neptune that led to the discovery of Uranus.

Schemata in Comprehension and Interpretation

The most important role of schemata in the process of science is in the area of comprehension and interpretation. One of the major areas of agreement in modern philosophy of science and contemporary cognitive psychology is that two people can have very different cognitive interpretations for the same data.

Evidence from Psychology

Schema vs. nonschema. There are a number of experiments that show the role of schemata in comprehension by contrasting the comprehension of information with and without an appropriate schema For example, Bransford and Johnson (1972) found that subjects listening to an obtusely written passage showed much higher comprehension and memory when given information about the topic (e.g., "the paragraph you will hear will be about washing clothes") than when not given the information about the topic. In another study Bransford and Johnson (1973) showed that comprehension and memory for apparently anomalous sentences (e.g., "The notes were sour because the seam was split") was considerably improved when an appropriate schema was supplied (e.g., bagpipes).

Alternate schemata. Another aspect of schema-based comprehension occurs when the data can support two alternate interpretations. Anderson, Reynolds, Schallert, and Goetz (1977) investigated the comprehension and memory of an ambiguous passage (playing cards vs. music rehearsal) by music education majors and by nonmusic majors. They showed that the background schema held by the two groups led to very different interpretations. A series of multiple choice questions showed that the music majors interpreted the passage in a schema-consistent way as a passage about a music rehearsal while the nonmusic majors interpreted the same passage as being about a card game.

Vosniadou and Brewer (1992) have investigated young children's beliefs about the shape of the earth. They have shown that most very young children (3-5 yrs.) believe that the earth is flat and then, under the impact of information from adults that the earth is round, come to develop a variety of theories about the shape of the earth. The Vosniadou and Brewer data show that early elementary school children hold a wide range of models. Some children believe that the earth is a disc, some that it is a hollow sphere, some that it is a sphere, and some that there are two earths, a flat one people live on and a round one up in the sky. These results show that children can hold very different interpretations for the same set of data.

Thus, it appears that schemata can serve to provide an interpretation for previously uninterpretable information and that alternate schemata can be applied to the same information.

Examples from the History of Science

Schema vs. nonschema. One of the major roles of scientific theories is to provide explanations for previously unexplained information. Thus, before the theory of plate tectonics was developed, the shapes of the west coast of Africa and the east coast of South America were thought to be due to random historical events; however, after the theory was accepted the complementary shapes of these continents was interpreted as evidence for continental drift (Hallam, 1973).

Alternate schemata. Much of the history of science involves debates about the theoretical interpretation of a particular set of data. One of the most obvious cases is the differential interpretation of the motion of the solar objects within a Copernican or nonCopernican theoretical framework (Kuhn, 1957).

Schemata in Memory

Another psychological process where schemata play a large role is memory. This is an area that has been extensively studied in cognitive psychology but rarely mentioned by philosophers of science.

Evidence from Psychology

There are many studies of the role of schemata in the memory process (see Brewer & Nakamura, 1984, for a review). These studies show that: (a) information that instantiates a schema is better recalled than information that does not; (b) schema-related information is better recalled than schema-irrelevant information; and (c) information that does not fit a schema tends to be distorted in recall to be consistent with the schema.

Examples from the History of Science

There are many examples in science where the subsequent description of a published experiment or finding does not agree with the original. For example, in an influential article on the impact of language on thought, Whorf (1940/1956) gives the number of words for snow in Eskimo as either 3 or 7. Martin (1986) has shown that there are published accounts that put the number as high as 100.

Harris (1979) has shown that secondary accounts of a widely cited study by Watson and Rayner (1920) on the classical conditioning of a child show dramatic distortions. Cooper (1935) has shown similar distortions in accounts of Galileo's (purported) experiment with falling objects from the Tower of Pisa.

In a recent paper Vicente and Brewer (1993) argue that since it is easy for a reader to check original sources and since there is a scientific norm that requires accurate reporting of experimental work, it is unlikely that these errors are deliberate and instead is more likely that they are due to schema-based memory errors on the part of scientists. Vicente and Brewer provide empirical evidence for this hypothesis. They show that there have been a large number of errors in the citation of a particular experiment by de Groot (1965) on memory by chess masters for chess positions. They show that most of these errors have tended to be schema-based and that when undergraduates read the original accounts of this experiment and are asked to recall it, their memory errors reproduce almost all the errors found in the published literature.

The consistency between the schema-memory research and the analysis of the published literature suggests that there are strong schema effects at work in the memory process of scientists. In fact, it may be, as Kuhn argues, that scientists with different theories live in "different worlds," but perhaps the different worlds are the different worlds as interpreted *and remembered* by the scientists with different theories.

Implications for the Philosophy of Science

Theory-Laden Observation

It seems to us that our analysis of the experimental and historical evidence converges on a clear account of the role of theories in observation. There is convincing evidence that theories can influence perception, so the evidence supports the Hanson and Kuhn position against the earlier positivist views that sensory data provides an unassailable basis for science.

However, the evidence also suggests that top-down influences on perception are only strong when the incoming sensory input is weak or ambiguous. Thus, in cases where the bottom-up sensory evidence is strong and unambiguous there is little evidence that theory can override observation and so the evidence does not support the strong form of the theory-laden position that is sometimes attributed to Hanson and Kuhn. This top-down, bottom-up synthesis seems to us to be a resolution of the issue that is consistent with the experimental and historical evidence and one that is consistent with the beliefs of most working scientists.

Limited Focus on the Psychological Process of Observation

The other major conclusion we draw from our analysis is that previous discussions of the theory-laden nature of observations have adopted a much too limited view of the mental processes involved in science. For example both Kuhn (1962, ch. 10) and Hanson (1958, p. 5, 7) discuss the example of a Copernican and a nonCopernican looking at the sun and argue that they would see different things. Our analysis suggests that they would have the same perceptual experience, but would interpret the information differently.

Our more detailed analysis of the psychological processes involved in carrying out science suggest that the work in the philosophy of science has focused too strongly on perception. We show that theory can influence a wide variety of psychological processes--perception, attention, comprehension and memory. In interpretation, and memory, theory *can* override sensory information, even when the sensory information is strong. Our work suggests that it is possible to carry out much more precise investigations into the role of theory in the scientific process.

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