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Science, environmental risk assessment, and the frame problem.

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Using a dichotomized framework for formulating scientific questions may be dangerous because it assumes only a negative or positive answer to the hypothesis. The way the questioned is framed influences the answers derived from the inquiry.

How scientists frame their questions often controls their answers. For example, suppose two biologists 30 years ago were observing the same phenomenon, the protozoan Amoeba, and they both ask the question: What is it? Suppose one biologist asks the question within the frame of one-celled animals. Suppose the other biologist asks the question within the frame of noncelled animal (Hanson 1958). Their different frames, different ways of conceptualizing the question, would control their respective answers. Different frames may be thought of as different sets of theoretical assumptions for structuring the same data (Fetzer 1990, Minsky 1981).

The different conceptualizations or frames of the two biologists include different views about the significant problems to be solved, the relevant data, and what counts as an answer to the question, What is it? On the one hand, the biologist 30 years ago who used the frame of one-celled animal would have seen Amoeba in all its analogies with different types of single cells. He would have seen it as resembling a liver cell, a nerve cell, or an epithelium cell. Each of these cells has a wall, nucleus, and cytoplasm. Within the class of single cells, this biologist would have seen Amoeba as distinguished only by its independence. On the other hand, the biologist 30 years ago who used the frame of noncelled animal would have seen Amoeba as an entire animal. He would have seen it as resembling all whole animals--ingesting food, digesting it, assimilating it, excreting waste, reproducing, and being mobile. It would have been distinguished by its small size. Because each scientist would have had a different frame for raising the same question about Amoeba, each would have had a different view about what counts as an answer to the question.

Today, most biologists would use the frame of one-celled animal to describe Amoeba. Nevertheless, many answers to contemporary questions in science are dominated by the frames in terms of which we ask them. Biologists might obtain different answers depending on whether they observed a phenomenon in terms of the frame of single cellularity or multicellularity. Hence, whoever frames the question often controls the answer.

The two-value frame

Some of the most basic scientific frames concern inductive methodology--when and how to interpret data as providing grounds for accepting particular hypotheses. For example, scientists frequently use a two-value frame for hypothesis acceptance. When answering the question of whether to accept a hypothesis provisionally, they often frame the question by assuming that there are only two responses they can give: yes (because the hypothesis has been confirmed) or no (because the hypothesis has been falsified). Scientists using a two-value frame also often assume that, if rigorous testing fails to falsify some testable hypothesis (e.g., organic molecules can come in right- and left-handed mirror-image versions), then it is reasonable to accept it provisionally.

Although scientists frequently employ the two-value frame, there are many serious problems associated with using this frame to answer questions related to environmental risk. For example, suppose we are evaluating a hypothesis about whether some potentially hazardous technology is safe. Responding either yes or no could be dangerous. Using the two-value frame could lead to minimizing uncertainties and therefore to simplistic, perhaps disastrous, consequences. Because of limited data, questionable theories, or a variety of unknowns, scientists often cannot simply use the two-value frame and answer yes or no when they are asked about the acceptability of some complex technological or environmental risk.

The rationale for the two-value frame

Scientists frequently accept the yes-or-no frame because rigorously attempting (and failing) to falsify a precise testable hypothesis often provides grounds for accepting it (Popper 1968). For example, consider this hypothesis: there are no black bears living within the 554 acres of Muir Woods (California) National Monument. If ecologists rigorously used reliable methods to detect black bears there, and failed to find any, they might have grounds for accepting the hypothesis. In other words, they might assume the two-value frame is adequate, because repeated failure to falsify a testable hypothesis is often grounds for accepting it. Scientists also attempt to devise crucial experiments, tests that will enable them to use the two-value frame and answer yes or no to provisional acceptance of a hypothesis. Crucial experiments are tests for which two mutually exclusive, exhaustive hypotheses predict conflicting outcomes. Although rare, classical examples of crucial experiments are Millikan's attempt, in the early 1900s, to show whether electric charges are integral multiples of the charge of the electron (Millikan 1917) and Lenard's 1903 test concerning the light energy that a radiating point can transmit (Frank 1962).

A second reason that scientists sometimes use the two-value frame is pragmatic. As Duhem (1982) recognized, they provisionally accept a precise hypothesis, even one with obvious deficiencies, if there is no better (more probable) hypothesis available. Because most hypotheses can never be confirmed conclusively by testing all cases (Carnap 1966), scientists sometimes opt for provisional acceptance of the best available hypothesis.

A third situation in which scientists use the two-value frame is when they give provisional acceptance to null (no-effect) hypotheses that survive rigorous attempts at falsification. Because scientists traditionally have been more interested in avoiding false positives rather than false negatives in situations of uncertainty, they typically place the greater burden of proof on the person who postulates some, rather than no, effect. For example, they place the greater burden of proof on a geologist who postulates the effect that the water table will rise at a given location by at least 500 meters over the next 10,000 years, rather than on the geologist who postulates no such effect. Although accepting no-effect hypotheses runs the risk of false negatives, scientists usually assume that false positives are worse. As in criminal law, they presuppose that null hypotheses are provisionally acceptable (innocent) until they are rigorously falsified (proved guilty).

Using the two-value frame in risk assessment

Because policy makers often need immediate yes-or-no decisions about potential environmental threats, scientists have used the two-value frame in many risk assessments--from studies of hazardous landfills to childhood exposure to lead (Cranor 1993). To illustrate the dangers with using the two-value frame in such situations, however, consider the 1992 Early Site Suitability Evaluation (ESSE) completed by the US Department of Energy (DOE) for the proposed Yucca Mountain (Nevada) nuclear waste repository (Younker et al. 1992b). The repository is being planned as the world's first facility for deep geological disposal of high-level nuclear waste and spent fuel (Lemons and Malone 1991). The ESSE evaluated whether the site will be safe for the next 10,000 years, the time during which the high-level nuclear waste will be most dangerous. Despite major uncertainties about the precise, long-term hydrological and geological behavior of the site, the 1992 ESSE reported that Yucca Mountain was suitable. ESSE scientists, however, appear to have drawn this conclusion only because they were forced to use a two-value frame to assess the hypothesis that the site is suitable. The ESSE authors explained:

[C]onclusions about the site can

be either that current information

supports an unsuitability finding

or that current information supports

a suitability finding. . . .

If . . . current information does not

indicate that the site is unsuitable,

then the consensus position was

that at least a lower"level suitability

finding could be supported

(Younker et al. 1992b, pp. E-5, E-11).

To understand why the two-value frame for assessing the Yucca Mountain site-suitability hypothesis may be problematic, recall that scientists typically use the two-value frame to give provisional acceptance to a hypothesis, provided that at least one of three justifications is met: the hypothesis has survived rigorous and precise attempts at falsification; the hypothesis that has survived is the best of candidate hypotheses; or the surviving hypothesis is a null hypothesis.

At Yucca Mountain, none of the three justifications for use of the two-value frame is met. The long time period (10,000 years of site suitability) precludes the precise predictions necessary for rigorous attempts at falsification. Indeed, the 14 internationally distinguished scientists (who served as ESSE peer reviewers) unanimously warned:

[M]any aspects of site suitability

[at Yucca Mountain] are not well

suited for quantitative risk assessment. . . .

Any projections of the

rates of tectonic activity and volcanism,

as well as natural resource

occurrence and value, will be

fraught with substantial uncertainties

that cannot be quantified

(Younker et al. 1992a, p. B-2).

The peer reviewers cautioned that, although "there is . . . currently not enough defensible, site-specific information available to warrant acceptance or rejection of this site" (Younker et al. 1992a, p. 460), nevertheless they were forced by DOE to use the two-value frame regarding site suitability. The peer reviewers were not allowed to use a three-value frame, which would include yes, no, and no decision (inadequate information). As the peer reviewers explained:

The DOE General Siting Guidelines

(10 CFR Part 960) do not

allow a "no decision" finding. . . .

Thus the ESSE Core Team followed

the intent of the guidelines

(Younker et al. 1992a, p. 460).

The peer reviewers' warnings about inadequate site information and DOE's forbidding a no-decision finding (Younker et al. 1992a) both suggest that using the two-value frame at Yucca Mountain might beg important questions about safety and site suitability, because condition, regarding rigorous testing, cannot be met. To avoid begging these questions, a three-value frame might be preferable for evaluating environmentally risky or hazardous sites.

The second justification for using the two-value frame, that the nonfalsified hypothesis be the best available, likewise appears problematic in the Yucca Mountain case. Current assessments of Yucca Mountain suitability neither compare it to other proposed nuclear-waste sites nor do they compare the site-suitability hypothesis to the no-decision hypothesis for Yucca Mountain. Hence, it is impossible to tell whether Yucca Mountain is the best available site. Complete comparative analyses of proposed repository sites, for example, were precluded by the 1987 amendment to the Nuclear Waste Policy Act. It named Yucca Mountain, Nevada, as the only candidate location for the nation's first permanent repository for commercial nuclear waste and spent fuel. Using the two-value frame to judge the Yucca Mountain site-suitability hypothesis as best, therefore, appears problematic for at least two reasons. First, alternative sites have not been compared. Second, different hypotheses about Yucca Mountain suitability have "substantial uncertainties that cannot be quantified" (Younker et al. 1992a, p. B-12).

The third justification for using the two-value frame--that surviving hypotheses should be provisionally accepted if they are null--also does not work in the Yucca Mountain case. That Justification falls here because provisional acceptance of null hypotheses is inappropriate when applied science is used in situations with potentially serious environmental consequences. Theoretical science, of course, frequently gives provisional acceptance to a null hypothesis and places the burden of proof on those arguing against it, because good research requires us to be scientifically conservative and to avoid false positives. Science applied to environmental risk assessment, however, often must place the burden of proof on those arguing for the null hypothesis, because applied science and public policy also require us to be ethically conservative and avoid false negatives. As the National Academy of Sciences points out (NRC 1983, 1987), applied science and public policy can be ethically conservative by taking account of the social and environmental consequences of research results, not merely their scientific consequences. Taking account of the social and environmental consequences of research requires us to avoid provisional acceptance of null hypotheses and instead to investigate potential risks affecting the needs, rights, and welfare of the planet and the public.

The third justification for using the two-value frame also seems inapplicable to environmental risk assessment because the public may deserve more risk protection than either the two-value frame or null hypotheses provide. To the extent that the public has limited financial resources/information, or bears inequitable or involuntary impositions of environmental health threats, it may deserve more risk protection than do the proponents of a particular null hypothesis regarding environmental risk (Shrader-Frechette 1991, 1993). For example, because more than 80% of Nevadans say they do not want their state to host the proposed Yucca Mountain repository for the nation's nuclear waste (Slovic et al. 1991), forcing it on them may entitle them to greater risk protection, to compensate for the involuntary and inequitable risk imposition.

Future generations, likewise, deserve more protection from potential effects of the Yucca Mountain repository than either the two-value frame or null hypotheses provide. First, future persons cannot exercise their consent to the facility. Second, future persons will bear the most serious risks from it. Current regulations require no repository monitoring beyond the first 50 years, although waste migration is more likely after than during that period. Similarly, in cancer risk assessment, potential victims of a false null hypothesis may need special protection. Many epidemiological studies are too insensitive--owing to small samples and the rarity of the diseases--to detect positive effects.

Because some groups need special protection, assessors should not use the two-value frame and provisionally accept the null hypothesis. Also, field studies of populations exposed to hazardous substances often involve more uncertaintles than do those based on theoretical models (Cranor 1993). For all these reasons, use of the two-value frame to justify acceptance of null hypotheses regarding potentially serious environmental risks is questionable.

Hypotheses versus decisions

Theoretical science and science applied to environmental risk assessment have different goals and consequences. These differences argue against using the two-value frame in evaluating environmental risk. Theoretical scientists usually evaluate the truth of hypotheses (e.g., convection currents have moved this geological plate). Environmental risk assessors, however, also evaluate the acceptability of risk decisions (e.g., this site is suitable for permanent waste disposal). As the National Academy of Sciences put it, "risk assessment must always include policy as well as science" (NRC 1983, p. 76).

Because the acceptability of environmental risk decisions includes nonscientific factors--such as social, economic, and ethical considerations--they may be more suited to a three-value frame that explicitly takes account of complexity and uncertainty. For example, classical methods of Bayesian decision making typically employ a three-value frame, in the sense of including a category for uncertain events or those on which we have inadequate information to make a decision (Luce and Raiffa 1957). Decision theorists also recognize that even a high probability that a site is suitable for some dangerous activity (like storing nuclear waste) may not be high enough if the activity could pose serious consequences for public or environmental welfare. Therefore, the presence of serious or environmentally risky consequences typically argues for using a three-value frame in evaluating scientific hypotheses.

Because of the dissimilarities between theoretical science and science applied to environmental risk evaluation, assessors may need to consider using three-value frames for decisions that do not satisfy the three criteria for use of the two-value frames. Regardless of the frames they choose, however, scientists and policy makers need to recognize the power of their frames. As this analysis of the Yucca Mountain ESSE suggests, whoever frames scientific and environmental questions controls the answers.

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