Framing Sensible Questions of Nature[1]

LAURENCE H. SNYDER, Dean of the Graduate College,
University of Oklahoma, Norman

I am, as you know, a geneticist. I have been exposed to considerable general training in biology, and to much specialized training in genetics. Yet I learned what I consider to be my most valuable scientific lesson from the casual reading of a popular book in an entirely different field. The book was "The New Background of Science", a popular volume on astronomy and physics, by Sir James Jeans. In this book Jeans makes a statement to the effect that it is frequently easier to get some sort of an answer from nature to a nonsensical question than it is to ask a sensible question to begin with.

As a researcher, this statement set me to thinking, and I have come to the conclusion that it is one of the most significant points that can be brought to the attention of the scientist and educator. It is my hope tonight to illustrate Sir James' point of view with examples from several fields of science, and to outline as best I may the criteria for a sensible question.

Let me choose first an example from my own field of genetics. Some years ago a popular question in biology was "which is more important, heredity or environment?" As long as the question was asked in this way the answers obtained from nature were inconsistent and ambiguous. It took us a long time to realize that the question, asked in this way, was a nonsensical question.

When, however, we reframed the question and asked "How much of the variation in this specific trait (e.g. dementia praecox) is due to differences in the genetic make up of the individuals concerned, and how much is due to differences in the environments to which they have been exposed?", we began to get sensible, understandable answers. Ordinarily it turns out that part of the variation is attributable to genetic differences and part to environmental differences. We are coming to realize that every trait is the cooperative result of hereditary and environmental influences. It is the task of the geneticist to evaluate these for specific traits in specific populations under specific environments.

For example, all rabbits have a layer of fat under the skin. In some rabbits this fat is white, in others it is yellow (a serious carcass defect). If we cross a rabbit with white fat with one with yellow fat, the offspring all have white fat. Crossing these together results in a second generation having three rabbits with white fat to every one having yellow fat. Obviously fat color is dependent upon a single pair of alleles, the factor for white fat being dominant. We can breed rabbits to be of either fat color as we may wish.

Moreover, we know how the factors act. The dominant allele results in an enzyme which breaks down the yellow xanthophyll which is ingested with green food, and stores it in the liver. The recessive allele fails to result in this enzyme, the xanthophyll is not stored in the liver, but is carried by the circulation to the peripheral layers of fat and stored there.

However, all this happens only if we provide our rabbits with green food. If, instead of feeding them mash and cabbage, for example, we feed them mash and potatoes, there is no xanthyphyll ingested and of course, no yellow fat.

---

[1] Invitational Address, The Oklahoma Academy of Science, December 8, 1951.

	GREEN FOOD	NON-GREEN FOOD
w	white	white
ww	yellow	white

Thus the difference between white and yellow fat may be a genetic difference if the environment is held constant (green food), or an environmental difference if the genotype is held constant (w w). Note that we are not distinguishing between a case where the laws of heredity operate and one where they do not, but merely between a case of constant environment and variable heredity, and one of variable environment and constant heredity.

Let us turn to a case in geography. In 1569 Gerhard Kramer, a Flemish map maker, published a map of the earth on a projection which has been known as the Mercator Projection. Mercator is the Latin name which Kramer adopted for himself.

This map has certain virtues and many defects. It primary quality is in the fact that parallels and meridians cross each other at right angles as they do on the globe and, accordingly, a straight line anywhere on the map at any angle presents true directions. Accordingly, this map greatly facilitates the determination of sailing routes. In fact, it is the best map for that purpose. Its major defect is a lack of uniform scale and hence distortion of areas. Geographers have been interested in having a map of the earth upon which the distribution of physical, economic, demographic and other types of data might be plotted so as to make comparison simple and accurate; in other words an equal area map.

Several good projections had been developed but each had serious faults. Until recently the problem has been approached from the purely mathematical point of view involving the representation of a spherical surface upon a plane, without engaging in distortions, but the answers were not significant from the geographer's standpoint.

Some years ago, Dr. J. Paul Goode of the Department of Geography, University of Chicago, reframed the question, asking, what is our objective in trying to plot a map of the earth upon a plane? The answer was clear and direct. It is to show land areas or water areas in a manner which would make areal comparisons possible. Thus the objective was shifted from the realm of mathematics *per se*, to a definition of the specific use for which the map was intended. The next sensible question was, how can we best obtain this objective? Again the answer was clear. It can be done by interrupting the projection either for "continent unities" or "ocean unities". In 1923 Dr. Goode published his Homolosine Projection. Since this publication, other geographers and cartographers have taken the cue from his invention and worked out various modifications along similar lines. Thus, after several centuries of effort to produce an equal area map of the earth, the objective has been attained by rephrasing the approach to the problem.

Now let us ask the engineer whether he has encountered any problems which were solved only after the original question had proved nonsensical and had to be reframed. I find no trouble obtaining engineering examples.

If we take a bar of material one inch square and apply a pull to it lengthwise, gradually increasing the pull until the bar breaks, we can define the maximum pull exerted during the test as the tensile strength of the material. If now we cut a sharp notch around a similar bar and repeat the experiment to see whether the strength of the bar is reduced in proportion to the amount of area cut away, we get some contradictory results. If the material under test is ductile, such as soft steel or copper, the reduction in strength is very little. If it happens to be a brittle material like porcelain or very hard steel, the reduction is very great—quite out of proportion to the area cut away. If we try again with a series of experiments to determine the largest force which can be applied and removed an indefinite number of times, we get a result showing that the bar has been weakened by the notch more than we can account for on the basis of the area cut away, but still do not get any very consistent results. The question was simply ambiguous.

If, however, we ask "What is the maximum value of dP/dA as compared with the average value P/A in the cases of the two bars, we obtain a sensible and practical answer, although the answer must be sought by means of the polariscope, and not by direct experiment.

Returning now to biology, early in the history of the natural sciences there was set up a differentiation between "plants" and "animals". As long as we are dealing with cows and corn, elephants and eggplants, zebras and zinnias, we encounter no trouble in classifying living things as one or the other. With the invention of the microscope, however, came the discovery of numerous small simple organisms which were not so readily classified. Thereupon arose a heated discussion. "Is this a plant or is it an animal?" This question is meaningless and leads nowhere. Progress was made only when the question was reframed to read "What are the characteristics of this organism? How does it behave under this environment—that situation?" The very same point applies to the meaningless questions right now being asked about viruses and phages: "Are they living or non-living?" Good research workers do not waste time seeking answers to such meaningless questions.

Let us search the field of education for an example or two. The question has been raised "Are objective examinations better than essay examinations?" As it stands, it is a nonsensical question. Only ambiguous and inconsistent answers follow. Finally the question was reframed. "What is it that we are trying to appraise? How can we best appraise these things as objectively as possible?" If our objective is to appraise the student's ability to write, obviously we must have a sample of his writing. If it is to test his ability to apply principles, or to draw inferences, an objective examination may appraise this far less subjectively than an essay examination. Or a combination of types may be desirable.

Again the question has frequently been raised as to the best class size. The question has meaning only if framed to read "What are the objectives of the course? What changes are we trying to bring about in the students? Is it memory of facts? Laboratory skills? Application of principles? Setting up of test situations? How do students respond in these changes to large sections; to small sections?"

Sometimes we are not really asking the question we think we are, but a subsidiary question. Are we justified in teaching geometry, let us say, because of the transfer of the discipline to every day situations? The answer as the question was interpreted was no, because no transfer occurred. However, the question asked really was "geometry *as it is now taught*". When we realize that the question is actually more inclusive, and thus include in it "Can geometry be taught in such a way as to result in a transfer of training?", the answer is "yes". The answer to the original question is then "yes, if it is taught in such a way as to provide for a transfer of training."

Let us take an example from medicine. In the disease known as pernicious anemia, there is a lack of mature red cells in the blood. However, it is found that there are more immature cells than usual in the bone marrow, where new red cells are formed. These do not mature. The situation is similar to that found in carcinoma, a kind of tumor. The question was framed by physicians "How can we control tumors: specifically this tumor?" Pernicious anemia was 100% fatal up to 1925, usually with a three year course. No logical answer was forthcoming to the question, for the simple reason that pernicious anemia is not a tumor at all. The true answer came quite unexpectedly from an entirely different source.

Dr. Whipple of the University of Rochester was making a study of bile pigments and the formation of hemoglobin, especially as influenced by diet. Fruits, vegetables and meat were variously used in experimental diets. By chance liver was tried. It proved to stimulate red cells to development and therefore increase hemoglobin.

Minot and Murphy immediately saw the application to pernicious anemia, believing at first that the stimulating hormone was produced in the liver. Later it was discovered that the hormone is only *stored* in the liver. It is produced by the pyloric glands of the stomach. Achlorhydria, a lack of hydrochloric acid due to the destruction of the glands of the main portion of the stomach may be followed by destruction of the pyloric gland, hence by a lack of the hormone, resulting in pernicious anemia. The achlorhydria is the result of a genetic factor. However the same result may be obtained from an absence of meat, milk and eggs in the diet, since proteins stimulate the glands of the stomach to activity. This is a good example of the interaction of hereditary and environmental influences.

The main point in this discussion of pernicious anemia is that here an accidental reframing of the question, almost at right angles to the original question, led to the answer. The good research worker will make use of this principle when the answers he is getting are ambiguous or inconsistent.

May I choose now an example from astronomy? Until the middle ages there was, as you know, a geocentric notion of the motion of heavenly bodies. How can one explain the motion of these bodies around the earth? (The question as originally raised was of course based on the premise that the planets and sun revolved around the earth). Thus the question was meaningless and had no answer because it was raised on the basis of a false premise. When the point of view was radically shifted from a geocentric to a heliocentric concept, the question suddenly assumed meaning and significance, and an answer was forthcoming.

Physics provides a number of interesting examples of my point. The electron has been the basis for the raising of many questions. To cite a very few of these will indicate another principle involved in the asking of scientific questions: the principle that a question which is nonsensical at one stage of development of a science may become sensible under other states of knowledge, and vice versa. In J. J. Thomson's time it was possible to ask "What is the mass of the electron?" What is its charge? Its volume?" To ask "What is its wave length?" would have been a nonsensical question. However, by the time of G. P. Thompson that question was perfectly sensible, and had an unambiguous answer. The question "What is the magnetic moment of the electron?" would have been nonsensical at that time, however, since the concept of spin had not yet been found to be necessary in the clarification of electronic phenomena. At present it is not at all a nonsensical question. Right now it would be a very nonsensical question to ask "How big are the ears of an electron?" My physicist friends assure me, however, that if in the future the concept of the electron's ears would help to clarify the observed phenomena, the electron will have ears, or wings, or consciousness, or anything else needed.

Again the question "How can we bring about the transmutation of elements?" has passed through stages where it was a sensible question for the alchemists, nonsensical to the orthodox chemists, and is now again becoming a reasonable question in the light of modern physical chemistry.

Let me turn to geology for my final example. Here the so-called Laramie problem offers an illustration of the fallacy that the answer to a question must be yes or no; or that one or the other of two alternative answers is possible, but not both, or a third answer.

In attempting to determine the boundary between the Cretaceous of the Mesozoic and the Eocene of the Coenozoic in western North America, the question asked about any given geological formation was "Is it Cretaceous or Eocene?" Actually certain formations are neither, but are transitional. Yet the question was repeatedly asked on the assumption that there must be a sharp break; that formations in disputed regions must be one or the other. Over every proposed line of break much profitless discussion arose, and much wasted argument ensued, since none of the proposed breaks is real.

As long as geologists labored under the concept that geologic eras are separated by world-wide punctuating disturbances, no sensible question was asked leading to the solution of the Laramie problem, since in the area of greatest dispute there is no break, and in those districts where the break is prominent, it does not come at a reasonable juncture between Cretaceous and Eocene.

Let me then attempt to set up the criteria for the asking of a sensible question of nature.

First, it should be stated in the terms in which the answer is desired. If a biological answer is wanted, the question must be asked in terms of biological abstractions; if a physical answer is desired, the question must be asked in terms of physical abstractions. You will recall the story of the little girl who was asked by her teacher "What is it that an elephant has that no other animal has?" Much to the teacher's surprise the child answered "Little elephants". That teacher had not framed the question in the terms in which she wanted the answer. This point so often becomes especially important when a scientist steps outside his own field.

Second, the question should be open-minded: not designed to "prove" anything. We can never ask of nature "Is this hypothesis true?", but only "Is this hypothesis tenable?" or "Is this hypothesis consistent with observable phenomena?" It has rightly been said that one phenomenon may be sufficient to disprove a hypothesis: a million million do not suffice to prove it.

Third, the question must be based on all available knowledge, and so designed as to clarify the existing phenomena. It is necessary to put first things first. If, for example, you wished to discover how far away the rainbow is, you might use surveying methods. Using precision instruments you would get a clear unequivocal answer: *minus* 93,000,000 miles. But this answer is obviously absurd, for how can a distance be negative; moreover 93,000,000 miles is certainly absurd, since you can see that rainbow is between you and that mountain over there. But if you reframe your question to read "How far away is the source of light which forms the rainbow?", the answer becomes suddenly significant. The minus value tells you that the source of light is not in front of you at all, but *behind* you, and the 93,000,000 miles immediately identifies it with the sun.

Fourth, the earlier questions in any investigation must be inclusive, taking account of various known or suspected possibilities. Early questions about the cause of malaria centered around the mysterious "miasma", the bad night air arising from swamps. And did not early experience seem to prove the causal nature of miasma, for excluding it tended to prevent malaria? Not until the possible causes were widened to include night-flying insects, however, was progress made in the permanent control of malaria.

Fifth, the later questions in any investigation must be more and more precisely stated: more crucial. Especially in dealing with living things the experiment must be guarded by adequate controls. It is important, however, to fully understand the limits of controls. The story is told of a famous psychologist who had four children. He baptized two, and kept two for controls.

Sixth, care must be taken to assure yourself that you are actually asking the question you think you are, and not some subsidiary question implied but perhaps not recognized. In the early study of the linkage of hereditary factors in human beings, investigators thought they were asking the question "Are these factors linked?", whereas they were really asking "Are these traits associated in the general population?", an association which may be the result of a number of phenomena, no one of which is in fact linkage.

The moral of this story is straightforward and clear. It behooves the research worker to scan the above criteria and any others which may occur to him, and make an honest effort to frame his question of nature properly: clearly, concisely. Then, if a clear understandable answer is not forthcoming he should ask the question again in another and better form. A question incorrectly framed in the first place will give some kind of an answer, but the answer may be inconceivably difficult to interpret sensibly.

It is not a crime against science to ask a nonsensical question. The very facts of our lack of knowledge and our human lack of perception make it inevitable that we should frequently ask nonsensical questions. The crime against science is committed when, having failed to get consistent or unambiguous answers from nature, we fail to alter our question, *or even radically to reframe it*. If we do not take this step, we fail in one of the most important steps of the scientific method.

BIBLIOGRAPHY

JEANS, SIR JAMES. 1933. The New Background of Science. New York, the Macmillan Co., viii+301 pp.