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Philosophy of Science: An Overview for Educators

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DESCRIPTION OF PHILOSOPHY OF SCIENCE AND ITS RATIONALE

From the point of view of knowledge (or epistemologically), science is a method of inquiry about the things and structures in the world. Conceived of as a social *human* activity, science is *an important institution or practice* Constitutive of the modern world. Science has been heralded for much of the good in the world and much of its progress. It has also been blamed for many of the world's problems. Yet, scientific knowledge is often held to be the major intellectual accomplishment of the Western world.

Bucks, buildings, best-selling books, museums, journals, and television programs are dedicated to science. Many people directly or indirectly earn their livelihoods by their participation in or connection with some aspect of science. Governments, corporations, and private foundations spend billions to support scientific research. Yet, despite science's multi-aspected ubiquity, there remain inadequately answered questions about what science is, how to characterize the nature of its practitioners' activities, and what is the significance of the whole enterprise.

Philosophy of science, in attempting to understand these issues, studies the activities of scientists and the nature and character of scientific theories. It looks at the structure of the practice and products of this peculiar human activity. The domain *examined is science and scientists* as they now are, once were, and, sometimes, as they might be. Philosophy of science is concerned with the methods that scientists use in discovery, and to elaborate and confirm theories. Also, the philosophy of science is concerned with the effects of science on the activities and interests of nonscientists *and nonscientific* institutions and practices that are part of society - past and present.

Why is philosophy of science important? Why is it worth understanding and thinking about? The simplest answer is also the best. Philosophy of science, like philosophy in general, is a discipline that tries to expose the underlying presuppositions that structure important practices and institutions of life. It subjects the structures of life and thought to critical examination. In short, it makes us think about what we are doing and why.

It scrutinizes the goals and purposes of human activities, then questions the methods and procedures by which those goals and purposes are attained. In doing so, it attempts to justify the goals and improve the procedures. Arguably, such self-conscious criticism of one's own practices is a distinguishing feature of intelligent human behavior. It might even be the best definition of intelligence.

In less abstract terms, philosophy makes people think about what they are doing. Philosophy of science takes science and subjects it to critical thought. Now part of the fun of science, as in most interesting human activities, lies in thinking about how and why it is done, and how it might be done better. In this way, philosophy is the discipline that studies the history *and structure of inquiry,* for asking critical questions that any curious and self-conscious practitioner would be asking. It goes further by attempting to systematically and rigorously examine and codify such questioning

From a disciplinary view within philosophy, philosophy of science raises more precise questions. Epistemologically, it asks what the nature and essential characteristics of scientific knowledge are, how this knowledge is obtained, how it is codified and presented, how it is subjected to scrutiny, and how it is warranted or validated. From a metaphysical point of view, philosophy of science examines the kinds and natures of things in the world, in so far as science deals with them. It critically analyzes the assumptions of scientists about the basic or fundamental physical, biological and social 'stuff' that we need to think about when trying to understand the world. Ethically, philosophy of science directs questions towards the value systems that scientists have and asks how these values affect the practices and conclusions of science, Ethical issues also arise in considering the effects that science has on the values of the people affected, directly or indirectly, by science. Other ethical dilemmas arise when considering how science affects decision making and problem solving. Interesting issues in political philosophy dealing with science policy and regulations and questions about *the aesthetic nature of scientific theories also arise in* the philosophy of science.

For our purposes, the epistemological point of view is paramount. Science, as it is taught and practiced in an educational setting, should be concerned with questions about the nature and adequacy of knowledge. It was from this point of view that W. V. 0. Quine once wrote 'philosophy of science is philosophy enough'.

From a pedagogical point of view, which is most crucial for this essay, asking students to reflect upon their activities when engaging in science, or studying science, is a way to enable them to understand themselves and their motivations more clearly. Having them ask - at whatever level - many of the questions that philosophers of science ask, actively engages them in the process of inquiry and challenges them to increase understand*ing* of what they *are doing. Reflecting* about the goals *and procedures of* problem solving helps one solve problems better. It also enables one to adapt and restructure old goals and procedures to new environments and problems.

Of course, there are dangers. Philosophy cannot be effectively taught as an abstract discipline to children. They do not have the capacity for abstraction and the maturity for comprehension that such tutelage would require. Therefore, philosophical questions must be raised in context and with regard to a specific content for its critical concerns to be efficacious. The concepts that I shall elaborate below as exemplary of the philosophy of science should therefore not be conceived as the subject matter of a course for school children. Rather, they should be seen as a set of terms and ideas for structuring questions and activities that develop motivation and intelligence while the students are investigating and actively working on some bit of scientific 'research'.

CONCEPTS IN PHILOSOPHY OF SCIENCE

The following are sets of interdefined and interrelated concepts that are basic to the philosophy of science. I have attempted to impose a structure by outlining some of the types of issues and then subdividing these into concepts typical of more specific investigations. The structure of this outline is somewhat artificial in that following almost any single general or particular item will eventually lead to all the others.

Aims and goals of science. The big questions deal with the motivations and purposes for doing science. Why do scientists do what they do? Why does society value science as an enterprise and therefore sustain and support it?

First and foremost, I believe, scientists, especially the good ones, engage in science because they are curious and have fun assuaging that curiosity through doing science. They get excited by their activities, mental and physical. Psychologically and pedagogically, awakening curiosity, fun, and excitement are most important, but these aspects of the motivations for doing science have not yielded well to philosophical or psychological explanation.

Most philosophical reflection about the aims and goals of science deals with the acquisition of knowledge and how that knowledge brings understanding. Science aims at understanding the physical, biological, and social world. This way of looking at science takes its goal to be explanation and the advancement of knowledge, and the psychological and epistemological effect to be understanding.

Many years ago, Francis Bacon articulated the goal of science as being the control and manipulation of the environment. From this viewpoint, scientists attempt to figure out how and why the structures of the world work so that people can utilize this knowledge to control, change and modifv the environment composed of those structures. Usually, the, justification for control and modification is given in terms of ethical or economic goals, or most importantly, the bettering of the quality of human like through the acquisition of knowledge.

Technological innovation is one of the ways in which control is made possible. The technological 'payoffs', often mistakenly thought of as part of applied science, are present in many contemporary justifications of science (and particularly, in justifying why scientific research should be funded).

Thinking about science as a form of knowledge raises questions about other kinds of endeavors which also make knowledge claims. One aspect of this comes up when considering the demarcation of science from pseudo-science (or, as sometimes put, rational inquiry as opposed to superstition or fad). There is much to say on this 'hot' issue, but basically, one goal of science and science education should be to have children understand the difference between good and bad science, between legitimate and fraudulent or flawed methods of inquiry and justification. This can be done without having to involve them in concerns about whether or not astrology is in any way a legitimate science, or whether the forms of inquiry and beliefs of the peoples of the New Guinea interior are “just as rational” as our Western ways. Thinking about these latter questions, and their ilk, requires sophistication, especially as they are often argued with political or ideological purposes.

Limits of science. Part of understanding the nature of scientific knowledge is understanding what science cannot do and what it does not aim to do. Probably the most important limit that needs to be stressed is the tentative nature of scientific knowledge. There are no absolute proofs. There is no absolute knowledge. The scientist must be open minded, nondogmatic and of a changeable mind when circumstances warrant.

One way of coming to understand this is by careful examination of examples of scientific change. Science has a history that shows that beliefs once held to be true and reasonable later come to be questioned and, sometimes, abandoned. What are thought to be unquestionable facts often times are later found to be not only not facts but even illusions. The very questions that scientists ask and what they ask them about changes too. This is true despite the fact that science is in many ways a cumulative endeavor and sometimes even has identifiable and understandable patterns of change.

Another aspect of the limits of science has to do with precision and accuracy. While these are admirable epistemic goals, the character of most scientific knowledge is approximate. Data are seldom unambiguous; interpretations and interpolations often occur. Also, the possibility of error and the limits of precision have to be understood as an intrinsic part of the method of investigation.

Yet another more diffuse sort of limit comes when science pretends to be the source of all knowledge that is worthwhile. Science courses should somehow make sure that science students learn that science is not enough. In fact, humanities and social science content ought to be part of all science courses in order to avoid this impression. Stressing the ethical and social dimensions of science will help accomplish this goal, in part.

Discoverv. Perhaps the easiest way of thinking about the phenomenon of scientific discovery is to think of the scientist as engaged in a process of inquiry by which he or she 'Puts questions to nature'. Discovery sometimes occurs when the answers that nature gives are unexpected. Other discoveries are more theoretical in character. Here, discovery comes when different domains of inquiry are unified or when new concepts are introduced into the explanations.

Explanation. Questions about explanation can be broken down and made more tractable by thinking about two questions: What kinds of things are explained? and What are explanations?

For the most part, science attempts to explain changes, not consistencies. Changes in motion, changes in a biological system, or changes in the social order command attention and require explanation. Explaining changes presupposes the possibility, or at least the ideal, that the uniform, normal or constant can be specified so that the changes and the reasons for change can be stated and, sometimes, measured against what is unchanging.

Scientific theories do not attempt to explain everything at once. The explanations given by science are proffered to account for specific types of events. The set of the event types that a theory explains is called its domain.

Some explanations deal with why certain items or events come to exist or remain in existence. Other explanations try to account for how and why certain systems function. 'Data' is the term generally used to refer to facts about which there is consensus and which are taken to be unproblematic. Though, as noted earlier, on occasion scientists question the reliability of data or, more often, they argue about how the data are to be interpreted and what they mean. What is an explanation? Scientific explanation is best thought of as a process by which a set of verbal or written utterances is presented to someone which leads to understanding about the content of the utterances. Questions about understanding and making sense are not easily explicated. It is easy, however, to provide synonyms for 'explanation' which help to shed some light on the psychological processes involved in explaining something to someone. Explanations try to make phenomena comprehensible. They attempt to tie disparate parts together into some coherent structure. They attempt to find display patterns (or maps) amongst facts and events. Basically, explanations establish relationships.

The relationships constituting an explanation have been described as relating the unfamiliar to the familiar, or by showing how what is unknown or not understood can be 'reduced' to what was previously known or understood. Explanations make events expected and not surprising. Explanations, on this type of model, come about when a preexisting mental structure, a schema or script, is applied to new data or to a different domain. The ways in which the schema or script can be applied include adapting or modifying the structure or simply applying it to now instances. Sometimes, explanations offer new schemas for understanding (as was suggested by Kuhn's paradigm shifts), but these new schemas, if they are to be understood, must relate somehow to the old. One cannot explain something based on nothing.

In more philosophical terms such explanatory relations are thought to arise when an individual phenomenon is subsumed under a universal law. This is the covering law model of explanation. The explanation occurs because the observed fact is seen, after subsumption, to be an instance of an already understood type; that is, the fact is an instance of the law.

Statistical explanations are an important type of explanation. Statistical explanations subsume a Particular event under some statistical law. They report the probability that one thing may be related to another. This has led some philosophers to consider explanations as the giving of assemblages of statistically relevant factors. On this view an explanation occurs when a property or fact is correlated with the other properties, events, or facts that are known to occur with some frequency along with the one being explained. Here 'explanation' is explicated in terms of statistical correlations. Such explanations are often regarded as incomplete because they do not give causes. It is important here to stress that only some correlations are significant and to learn some simple rules that allow for deciding whether a correlation is worth asserting or not.

Causal connections are often contrasted to statistical correlations. Causality is often thought to be the key to unlocking the secret of explanation. An explanation occurs, many philosophers believe, when the causal circumstances leading up to the change or responsible for the fact are described. The provision of the causal chain explains why the change or fact came about. Often, providing a causal chain involves describing a mechanism whose operation brings about the phenomenon to be explained. Mechanisms are particular types of systems whose parts function to make clear how a change occurs or a phenomenon occurs, Mechanisms often are items arranged in spatial displays connected by forces (contact or other). Sometimes these are called models.

Finally, explanations have been thought of as answers to why (or how) questions. This had led some thinkers to attempt to account for the phenomenon of explanation in terms of an interrogative (question asking) model. On this view if we understand why some answers to questions are satisfying or put our unease (that led to the question) to rest, then we have understood explanations. Usually these interrogative models end up relying back upon some more basic notion of comprehension or understanding, which is the answer they give as to why the question is felt to be answered.

Theory, law, model and hypothesis, paradigms and research traditions. These terms are most often used to describe the vehicles by which scientific explanations are carried. They can also be thought of as terms describing how scientists describe or write down the results of their investigations, They codify the results of scientific inquiry into written structures that are meant to be intelligible, There is very little pattern or consistency in the use of these terms.

One of the major issues deals with explanatory terms occurring in a theory. 'Realism' holds that at least some of the terms in the theory refer to objects and events in the real world, and that the postulated mechanisms that are described in theories are meant to really exist. The alternative view of theories, instrumentalism, holds that theories are devices for correlating data and serve as mere instruments for calculating or summarizing these correlations. On the instrumentalist view theories are structures for 'saving the phenomena', that is for showing when correlative phenomena can be expected to co-occur (or with what frequency they will do so).

A more applicable wav of looking at the realism-instrumentalism debate is to ask how the terms in theories function in an explanation. For many purposes in science, the interesting terms in the theory are represented as variables. In such a case the question becomes how to interpret the variables (where variables are part of the mathematical language in which laws and theories are presented). Some variables are thought to refer to real entitles or processes, others to be mere calculating or summarizing devices, while still others are idealizations.

When one moves from talking about individual theories and laws to successive sets of these, and begins asking why theories change over time, questions arise about scientific progress and the cumulative character of science. Some philosophers have introduced units that are larger and less specific than theories in order to attempt to understand scientific change and progress. These nave been called paradigms or research traditions (sometimes, even, world views). As theories or paradigms succeed one another, and scientific change occurs, is there any definable, sensible notion of progress that can be articulated? The idea of scientific progress as a linear, fact-by-fact, theory-by-theory accumulation is often assumed in science textbooks as central to the nature of science. Scientific progress is often described in a way that contradicts the tentative character of scientific knowledge stressed above.

A 'model' may be conceived of as a partial theory. The model's internal structure represents only some properties and relations of the phenomenon or mechanism being modeled. Usually models are treated more tentatively than laws or theories (which are taken to be better established).

A 'hypothesis' is a conjecture put forward to be tested or to account for some data. The word is also sometimes used to refer to the theoretical assumptions underlying an experimental design. Often times the idea of tentative character of a claim is stressed by choosing this word to characterize the claim. Very often though 'hypothesis' and 'model' are used interchangeably, and sometimes even 'theory' and 'law' can be used with the same meanings.

Evidence, test, confirmation, falsification, and prediction. The concepts of evidence, test, confirmation, falsification, and prediction concern the process of justification or warranting in science. They are ways philosophers have tried to describe the adequacy and efficacy of the laws, theories, and research traditions of science.

The conceptual key here is that science is supposed to receive its warrant from the world by the procedures of empirical testing. Since a scientific theory is supposed to explain the why of what goes on in the world, the adequacy of a theory's explanation must be tested by appeal to what happens in the world. On some accounts, the very meaning of the terms occurring in scientific theories was given by their relation to terms that were used to describe observations. Observations, reported in observation terms, verified (showed to be true) the explanatory concepts of the theory. The testability of scientific hypotheses and theories is taken to be the chief feature that demarcates science from non-science. Non-science is warranted on non-empirical bases, i.e., on grounds that only spuriously relate their claims to observation and test.

Experiments are types of empirical tests. Experiments, most of the time, are designed to show how a theory or a hypothesis connects to the individual events in the world. In this way, they are designed to test predictions drawn from a theory or hypothesis. A prediction is an implication drawn from a theory or hypothesis that describes an event not yet observed. Experimental predictions are about individual occurrences that the experimenter thinks will be observed.

Philosophical problems dealing with confirmation, prediction, and testing are numerous. Exactly what is the relation that should exist between a theory and its confirming evidence? When does an observation or experimental result count as evidence for a theory? Do all theories have to have implied predictions? Moreover, it is argued that theories constrain what is to be observed and in many cases provide the vocabulary in which to describe the observations, or what comes to the same, observation terms are theory laden. This means that observations' neutrality for testing a theory or for deciding between theories is suspect.

Practical problems of confirmation and testing often depend on the adequacy of statistical methods and the conditions of their use, To cite one common instance, even those who use statistical packages to evaluate their research often do not know what statistical significance really means, or why they set the levels of significance as they do. Other problems have to do with the interpretation of variables and whether the experiments totally support the theoretical claims that are supposed to be based upon them; another problem is when one considers how experiments are designed in order to support explanations or test models, and whether they really do so.

Social, cultural, political and ethical implications. In this age, when science is becoming an increasingly intrusive and important part of all our lives social, ethical and political questions about science take on increasing urgency. The briefest account of these issues that I can make, concentrating here on ethics, divides ethical problems into problems about the values of scientists and problems about the value and effects of science as an institution and practice. Both are extremely important and both need to be a part of any adequate training in thinking about science.

The ethical values of the scientist are important in doing science. The characterization of scientific knowledge as tentative and changing means that the scientist has to have an open mind. A scientist cannot dogmatically hold onto cherished theories in the face of new evidence. He or she must value free inquiry. And, most of all, scientists must be honest and have developed a sense of what is scientific dishonesty or fraud.

Science, insofar as it is a profession that is dedicated to advancing society's knowledge, must also be cooperative. That is, information must be shared and peer critique must be encouraged. It is arguable that knowledge only can be advanced in this way, but it is certain that not sharing knowledge contradicts the goal of the advance of knowledge for the scientific community (as opposed to the individual).

The other set of ethical issues relating to the scientist has to do with the scientist's responsibilities regarding the uses of scientific knowledge. What limits ought there to be on

the types and uses of scientific research? What responsibilities does the individual scientist have towards those who fund the research or towards those who may be affected by it?
Some of these ethical questions about the responsibility of the individual scientist carry over into the ethical questions about science itself. Many scientific discoveries, theories, technological spinoffs, and practices affect the lives of many people. So here the basic question has to do with how particular scientific practices affect the quality of life. These questions are particularly acute today in medicine.

Other ethical dimensions of science deal with issues about allocating scarce resources, or what to spend money on. Should we be supporting a defense department poison gas research program at the expense of the country's homeless, or launching another space probe when the money might be better spent on the war on drugs? Of course, putting the questions in terms of such oppositions is. a very unrealistic way of setting up allocation problems.

Social, political, and ethical considerations are very broad and far reaching, but also very important. Students must be sensitized to understand that science is a human activity, and as such has ethical and social implications. If we train scientists who are unaware of these dimensions and the urgent and critical aspects of their impact, we ourselves will be morally culpable.

A BRIEF SKETCH OF SOME CASES AND EXAMPLES

Almost all the concepts used in the philosophy of science appear in one form or another in most scientific activities. In some cases, some aspects appear more conspicuously, but since the concepts are universal there are ways in which they can be used to describe all instances of scientific pursuit. Thus any case study or example can be used as a vehicle to bring up discussion of the concepts in philosophy of science.

The idea in both these sets of cases sketched below is to show students that science is not an isolated learning experience. The concepts and ideas, both substantive and methodological, used in one domain must be applied in other domains. Also, pedagogically, these examples and cases allow for the students to engage in various active forms of research and become involved in doing science. Then they should be encouraged to think about what they are doing, which is as I said when I began, the goal of philosophy of science.

Case study 1: Mechanisms. Galileo used Archimedean simple machines as models for understanding all motions, e.g., falling bodies and pendulum clocks were shown to be equivalent mechanisms and analyzable by equivalent mechanical models (as was the inclined plane and problems dealing with floating bodies). A way into this use of models as explanations for motions can come by having students think about time, using watches to illustrate measuring, and the mechanisms of clocks to illustrate motion and the idea of mechanism. (This case also introduces the tinkering aspect, now virtually lacking in contemporary society, which has been important in exciting curiosity among kids who later went into science.) Pendulum clocks are especially good for this example, but mechanical spring watches will do just fine. Kids must actually dissect the watch and learn the mechanism. (Digital watches cannot be used.) The point is to explain the movement of the hands by examining the regular period of the pendulum and how it drives the mechanism internal to the clock.

Further developments of these concepts could extend the use of the model to considering man as machine in various aspects, for example, biological functions such as the heart as a pump. Social concepts can be illustrated by considering team sports which in order to succeed must 'run like clock work'. For example, a football team can be analyzed as a social organization where all the parts (players) have a function to perform. The mechanism here is the organization of the persons in the social group as ordered by the plan that is supposed to determine their behavior. Considerations of ethical or normative judgments such as how well the team performs its function, and whether there should be team sports or professional sports at all, can be introduced here easily.

Case study 2: Equilibrium. Introduce a home-heating system as a servomechanisms involving equilibrium. The thermostat is a regulator controlling circulation of heat. The mechanism of the system explains why heal the home is kept at a constant temperature. Understanding the mechanism allows for predictions as to what will happen if the setting is changed.

Similar considerations can be raised about many biological systems, for example, the circulation of the blood or the respiratory system (or, more generally, the nutrition system - food circulation). A social example of circulation which would have appeal is the circulation of money, or more generally the trade system. This would be an introduction to basic market knowledge as well as discussion about the types of commodities that can be circulated and how equilibrium is reached in a market economy. This case can also be used easily to raise ethical and social questions.

ADDITIONAL READING

A good introductory text that makes use of historical examples is George Gale, *The Theory of Science,* McGraw Hill.

For more detailed and professional treatments of the topics touched upon in the essay the interested party might look at the readings contained in B. Brody & R. Grandy (eds.), *Readings in the Philosophy of Science,* 2nd edn., Prentice Hall.

A narrative version that provides an informative and high-level discussion of many of the contemporary issues in philosophy of science can be found in F. Suppe, *Introduction to Structure of Scientific Theories,* University Illinois Press.

Finally, there is a text that deals at length with the main areas in philosophy of science, so see the chapters in M. Salmon et al. (eds.), *Introduction to Philosophy of Science,* by the Department of History and Philosophy of Science, University of Pittsburgh, published by Prentice Hall.