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A Study in Philosophy and Goals of Science Education

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An inquiry into the philosophical area of any human endeavor results in the framing of "why" questions. Why study science at all?, naturally becomes one of these questions which has great relevance to the field of science education. "How" and "what" questions generally use up most of the science educator's time and efforts. This is not an attempt to negate the importance of "how" and "what" questions (they are the stuff of science); rather, it is an attempt to determine what the case for science is in our educational process.

From the very beginning, man, the intellectual, has been wondering. This wonder gave rise to concern regarding the explanation of his natural world. Early explanations of this natural world often resulted in fantasy, a reliance on gods, and a perpetuation of irrational thinking. This type of thinking certainly cannot be condemned, least of all by anyone who was not there at the time. This was their place in time and space, not ours. Even as recent as the time of Galileo, when he asked the professors in Florence to look through his telescope and to observe for themselves the satellites of Jupiter, "they would neither see them nor the telescope" (18). Bruno, in 1600, was burned at the stake for subscribing to a belief in the infinity of the universe and the possibility of many inhabited worlds. However, these tragic episodes involving science and scientists were few compared with tragedies concerning other cultural forces, religion, economics, etc. And yet, without the comparable internal tensions associated with governmental or religious revolution as we know it, even science had its own revolution which brought about the modern age of science. This age was pushed to the forefront by the likes of individuals who firmly believed in the orderliness of nature. Nash says, "One cannot progress, or even think of progressing, in scientific understanding if he considers nature ruled by one or more capricious or even actively malevolent deities." Or as he quotes Einstein, "The Lord God is subtle, but malicious he is not." Huxley, the agnostic and believer in the primary of evidence adds, "A moral purpose I see no trace in nature. That is an article of exclusive human manufacture."

Now we must consider that this is the here and now. It is *our* time and place. Science no longer has to beg for public support, financial or otherwise. It is a prime force in our entire society. Thus, its obligations are paramount if this position is to result in the common good.

A Philosophy of Science Education

A single broad statement of philosophy is difficult at best, but the one the writer will attempt to expand and defend is as follows: "To Provide the Opportunity for Scientific Literacy."

This statement of philosophy will be treated and defended in terms of broad goals for science education, the achievement of which should be relevant and contributory to the fulfillment of the philosophy.

Literacy must be thought of in the fullest sense, from one with the ability to read and write to the cultured man of letters.

Goal Number One: To Advance the Individual's Capacity for Rational Thought

The true "rationalist" or the individual who subscribes completely to "rationalism," if science is his particular area of interest, may be just a thought scientist or at most a paper scientist. His concern is to appeal to reason. His thoughtful reasoning is, of itself, knowledge, superior to and independent of his sense perceptions. Thus, we have here a part of science that is not based on observation.

Science has as its obligation to make its ideas, phenomena, and the predictive and "postdictive" results of its theories observable to the human senses. This is, specifically, also the obligation of the empiricist and more emphatically of the observationalist. This obligation does not necessarily apply to the rationalist. "He has the tendency to elaborate theoretical systems without much reference to the empirical meaning of concepts" (6).

The rational thinker in science presupposes some prior knowledge. The early rational thinker, when asked the question, "If one dropped a lightweight object and a heavier object from the same height above the earth at the same time, which would strike the earth first?", might very well say, "The heavier object, of course." This seemed reasonable to him—since all he knew was that objects fell toward the earth—and he wasn't particularly interested in whether it agreed with his sense observations at all. However, the later rational thinker, who now has the knowledge that any force requires an interaction between at least two or more objects, and that objects have inertia, might reason this way. If there is a gravitational interaction between objects, and in this case one object (the earth) is common to both the light object and the heavy object, and if one can apply only as much force on an object as it can apply in return, then isn't it possible that there is no more or no less capability to counteract the inertial properties of the lighter object than there is on the heavier object? Thus, the two objects should strike the earth at the same time. Here again the rationalist is not particularly concerned with whether the results of his thought agree with his sense observations.

Another example might be concerned with outer space. Since the moon, through all its phases, appears the same to the earth-bound observer (even

the rationalist), does this mean that the moon does not rotate on any axis of its own? If it does rotate, then both the rationalist and the empiricist (or observationalist) will probably agree that it must rotate in such a way that at any one time it presents the same observable area to the earth-bound observer. However, the side of the moon the earth observer cannot see, whether it is rotating or not, is unaccountable to the empiricist (or observationalist) because he simply cannot see it. (With orbiting satellite cameras, his dilemma is now resolved.) The rationalist can give thought to this question of whether or not the moon rotates on an axis with the following result: If the moon is rotating in such a way that it presents the same face to the earth observer, then it must be rotating at a relatively constant rate. This can lead him to two possibilities:

(1) The moon, from wherever it originated, upon entering the earth's gravitational field had an initial rotational velocity that was of such magnitude that it presented the same face to the earth-bound observer.
(2) The center of the moon's mass is not the same as its geometrical center. Thus, between two geometrical halves, there can be a relative difference in mass whereby, due to gravitational interaction, the more massive side will always be facing the earth.

If the moon is not rotating on its axis, then it is symmetrical at all points because the side or part of a side that the earth-bound observer sees always appears to be the same.

Rational thought alone is valuable, and the discipline of science lends itself to this type of inquiry.

The empiricist and observationalist are both rational thinkers. The true rationalist is pointed out here to emphasize his viewpoint that rational thought is sufficient, and through this contributes to science. However, he has not fulfilled the final obligation of the discipline. As P. W. Bridgeman says, "every meaningful scientific term must be either definable exhaustively in terms of a specific and unambiguous set of possible operations, or be itself a term denoting such an operation" (1).

Goal Number Two: To Advance the Individual's Knowledge and Understanding of the Natural Environment

"Our experience of the physical world, in particular, involves, in our perceptions, an orderliness and a reproducibility without which such experience could not be distinguished from fantasy or hallucination" (15).

Knowledge and understanding will be dealt with, utilizing two facets of science, (1) its logical structure and (2) its investigative nature and techniques.

Any disciplinary area of study makes use of its very foundations or fundamental theories over and over again. Thus, these foundations are continually under test and scrutiny. Philosophically one should ask, why has human endeavor progressed to a science, or a disciplined area of study, over the years? Presumably, the answer to this is that man simply wants to know. The ques-

tion, how does science contribute to knowledge and understanding of the natural environment?, therefore, will be explored.

It is the writer's contention that the search for knowledge is common to all. Everyone wants to know something; every one wants to know more; everyone is glad to have known. The difficulty seems to be in *talking* about how we know. This should not be. "There is always something wrong, if one is straining to make the commonplace incomprehensible" (17).

Prior to the existence of a "science" as we know it, the age of trial and error or empiricism was at the forefront and was, in fact, contributing to the scientific body of knowledge. Ancient metallurgical techniques were handed down from generation to generation, as were techniques of glassmaking, agriculture, food recipes. Even in very recent times, the antiknock gasolines had no theory to rely on; success was achieved by trial and error. Nevertheless, successful results were obtained that contributed to man's knowledge and welfare. However, generalizations from these trial-and-error procedures and results were usually weak and limited. They pertained mainly to the evidence of just the one specific case.

The exact sciences (physical science) have emerged into some fundamental patterns of meanings, whereby these patterns can allow prediction. Historically this seems to be the way science matures. They proceed from a largely empirical-inductive endeavor to a precise theoretical one. In this sense, the biological sciences do not seem as mature.

The logical structure and investigative nature of science, as they apply to the generation of knowledge, are interrelated. Structure implies that something is constructed in a certain way. Investigation can both inquire into this structure, as it has evolved through history, and contribute to its continuing evolvement.

The logical structure of science places reliances on facts, hypotheses, principles, generalizations, laws, and theories. While no sharp lines can be drawn between these, there are useful distinctions implied by them. "Facts" usually refer to particular data of observation. "Hypotheses" are generalizations in need of testing by further observations. "Principles" are fundamental ways of representing physical processes, suggesting further consequences to be tested by experiments and observations. "Generalizations" are hypotheses, whose scope of application has been well tested. "Laws" usually refer to generalizations that have been firmly established and precisely formulated. "Theories" are conceptual structures that provide *explanations* for laws.

For example, the study of the behavior of gases yields certain observable "facts" about pressure, volume, and temperature. Experiments can be performed to test the "hypothesis" that under constant temperature, when the pressure of a given mass of gas is increased, its volume will decrease. This hypothesis, when confirmed by experiment, becomes a valid "generalization." When quantitatively expressed by the mathematical relation $PV=K$, it qualifies as a law (Boyles). The "principle" implied here is that gases may be

treated as homogeneous compressible substances, with such measurable properties as pressure, volume and temperature (each specified within the experiment). The explanation for Boyles Law (and others, including Gay-Lussac's and Charles's) is provided by a theory (the kinetic theory of gases), which conceptually treats a gas as a collection of perfectly elastic particles in random motion. The same chain of knowledge generation can be applied to Mendel's observed facts about the patterns of appearances in garden peas, up through his laws of hereditary dominance and recessiveness to the theory of genetic continuity.

In order to be predictive, a science must have theory. Boyles Law, if the investigation stopped at that point, would be valid only if it were applied to each and every gas. However, the kinetic theory explains that Boyles Law must be applicable to all gases. Thus, all procedures up to theory may summarize or describe, but they do not explain, and thus do not seem to satisfy investigators as they search for basic explanations. As Robinson (15) quotes from Margenau ". . . they feel the urge to probe more deeply, to derive . . . (these uniformities) of experience from principles not immediately given."

Since science is both theoretical and empirical, the deductions must finally be checked against sense observations. This means that science has an obligation to be investigative.

There are a multitude of ways to investigate in science, none of which guarantees success. But one thing is clear, that in order to generate knowledge and maintain the dynamic nature of science, we must investigate as Conant (3) indicates:

> The more one studies the steps by which rapid advances have been made in the natural sciences, the more difficult it is to describe the ways in which wide generalizations and new concepts have originated. The one thing that does seem certain is that one must speak of the ways, for there is no single way. This is the reason why it is worse than nonsense to speak of the scientific method.

Some of the investigative processes which are valuable to the scientist and to the neophyte studying in the discipline have been outlined by the AAAS (18). These include observation, communication, number relations, classification, space/time relations, measuring, predicting, inference, interpreting data, formulating models, defining operationally, formulating hypothesis, controlling variables, and experimenting.

These mental and concrete investigative processes may be analogous to one of science's own processes, that of formulating models. All of these processes may be thought of as one model whereby one can proceed in science education. It is somewhat like a map. A map is a formal representation of an area, chosen for the purpose of directing travel in that region. So these processes may derive their usefulness in how they direct thought and eventual understanding of the natural world.

Investigation alone is insufficient. A union of rational thought, a knowledge

of the logical structure of the sciences, with investigation, is paramount. As Phenix (13) states,

> The goal of scientific investigation is not the accumulation of particular observations, but the formulation and testing of general laws.' To understand the methods of scientific inquiry, it is necessary to be clear as to how generalizations are obtained from the data of observation. The process is essentially indirect. Generalizations are not directly derived from the particulars of observation by a chain of logical inference. It is truer to say that generalization comes first, as an imaginative construction, and that the data of observation are then used to validate the generalization. In teaching science the importance of this priority can hardly be exaggerated. The student completely misunderstands science if he thinks that observations somehow speak for themselves, yielding laws and theories by some straightforward process of reasoning from the data of sense to the general propositions of science.

Hawkins goes on to say,

> Our understanding of things is attributive: the nature of anything is not merely a summary, but an explanation, of its natural behavior; the thing behaves as it does because it has such a nature rather than some other.

Goal Number Three: To Advance the Individual's Control Over His Conduct in a Civilized Environment

The crucial problem in civilization, as we know it, is man's behavior toward his fellow man. Science cannot divorce itself from this problem since man, as a biological entity, cannot isolate himself but must somehow exist alongside other human beings.

> We have to face first and foremost what is probably the chief anxiety now existent about the progress of science, namely, that it is giving man enormously increased power over his physical environment without at the same time conferring on him the wisdom to use this power for the well-being instead of the harm of his fellow human beings (11).

Scientists and nonscientists alike are becoming increasingly concerned with this cultural lag. In these times, there is a very definite sociological aspect of science, namely, cooperation in large-scale research programs, publication of research results, methods of scientific information retrieval, administration of funds for research projects and research fellowships, communicating the significance of science to the general public, etc. Obviously, scientist meets with scientist in all of these activities. However, the scientist must also deal with the nonscientist, mainly to convince him of the importance of science.

It is assumed that the scientist, by virtue of his profession, deals with his fellow man in accordance with a high moral tone and strict ethical principles. Whether he does this in actuality is always open to argument. However, scientists, like other human beings, must follow some rules of conduct to prevent them from being chaotic. In stable societies, these rules of conduct are usually held relatively constant by custom, and with continual refinement become codes of ethics.

Thus, what does science have to do with conduct or codes of ethics? Science

is concerned with the search for truth and fact, or "what is," rather than "what ought to be." There is the dilemma of human behavior and life itself. All life lives at the expense of other life. Even the vegetarian penalizes the animal by eating part of his food supply. The "will to live" seems to imply some unavoidable cruelty. This is evidenced by population controls, especially in impoverished communities, legalized abortion, the eradication of living organisms causing disease and savagery within the human race during wars, all of which display a great deal of cruelty while exercising the will to live. Fortunately or unfortunately, science has made great contributions to the sophistication of this inherent cruelty in man's need to survive, and will continue to do so. What then can science do to contribute to the conduct of man in his civilized environment?

"Man in his better moments seems to exemplify a senseless urge to force some order on his experience. The very existence of science is an example of this" (11). Science, through the self-evident truths of its axiom and somewhat more speculative assumptions of its postulates, continues then with its deductions to predict, infer, and conclude that certain things are indicative rather than imperative statements. Ethics, on the other hand, is vitally concerned with imperatives or commands concerning human beings, i.e., the human being ought to do so and so. The Golden Rule and the Ten Commandments are examples of imperatives that could be thought of as ethical laws. Our legal system, concerned as it is with the implications and actual practice of this theory, might be considered the ethical engineering portion. If science is to contribute to human conduct, then its concern might be to look for parallels or analogies within the scientific realm which may serve as imperatives regarding the human race, from which logical deductions may be drawn concerning human behavior.

Lindsay (11) and other scientists and philosophers of science have proposed a thermodynamic imperative as an ethical theory to which science contributes. This is based upon the first and second laws of thermodynamics. The first law states, in effect, that the total amount of energy stays constant. Again, some form of energy is always associated with an equivalent, corresponding loss, someplace. Thus, as far as energy is concerned, there is no way of getting something for nothing. The second law states that entropy (state of lowest energy or maximum disorder) cannot decrease by itself. It either increases or stays the same. Every time we decrease entropy we do so at the expense of energy.

The thermodynamic imperative states that through thought and behavior man should conduct himself so as to continually decrease or consume entropy. This means that he continually strives for maximum order rather than disorder. Man's institutions are examples of adherence to this imperative. Our educational systems, our legal structure, our government, our social institutions reflect this entropy-consuming tendency. There are numerous other behaviors of man that do not reflect this tendency, such as war, crime, alcoholism. . . .

The human organism, itself, seems to violate the second law of thermodynamics in that it is an ordered and an order-seeking entity. Thus, one might say, why not produce all the human life possible? This may happen, however, since we still have to obey the first law of not being able to get something for nothing, it seems to violate the imperative in that it is a disordered way of producing order. What this imperative asks is that the individual do all in his power to add to this order rather than subtract from it. This places a very heavy responsibility on the talented person, since he may be either a great consumer or producer of entropy. Therefore, the thermodynamic imperative applies to the individual, and he must be free to obey it or disobey it as he sees fit.

The development of science is imbedded in the social makeup of the world. Thus, it does impose its methods, inferences, predictions . . . on society, while the rest of society imposes its cultural patterns upon the sciences in a cyclic process. Science must contribute its share in the way of thought and technique to the continued quest for maximum order in our civilized environment, and to decreasing the gap between our technological advances and our cultural advances.

Goal Number Four: To Advance the Individual's Capacity for Productive Imagination

We cannot be taught imagination, but education must either expand or contract the native imaginative capacity of the individual. Thus, it appears that if we cannot be taught imagination, we really don't know what imagination is or what causes it. In terms of expanding or contracting the individual's native capacity for imagination, confinement to what imagination does and what science offers toward influencing its expansion or contraction appears to be the most fruitful procedure.

The observable characteristics in children, such as their fantasies, inattentiveness, dreaming (both day and night), and their unreal conceptions of the world, are often thought to be imaginative—and they are. However, these characteristics of imagination are of no real value to science. This is not to say that they are of no real value to the student. Almost every adult wishes that we could recapture some of these youthful capabilities, and he often does so when, during sleep, inhibitions disappear and he dreams. These are almost cathartic, and as such are of real value. However, the waking youthful fantasies or free-ranging imagination are of no use to science. Knowing too little and accepting too much, the child fails to discriminate between worthwhile, imaginative ideas about things as they are or might be and other ideas that are not. Supposedly, the educated man has this facility for critical discrimination, but he often pays a high price. Imaginative thought patterns may never occur to him or, if they do, they are pushed aside by his "critical thought" processes that have been so firmly established. As Nash (12) says, "Indeed a difficult feat, apparently rarely accomplished, is the acquisition of knowledge and

discipline without loss of essentially all of the child's facile capacity for seeing the familiar in unfamiliar ways."

The expansion of productive imagination within a student can and should be achieved through his encounters with science. This achievement is felt to be the responsibility of many of the new science curriculum projects. As Karplus (9) states, "The Science Curriculum Improvement Study may also shed some light on the acceptance by school systems and their communities of an educational program designed to create inquisitiveness, mental flexibility, and intellectual independence."

In the operation of science, we see that the scientist makes an observation and describes the reality he perceives. His imagination seems to direct him to look for regularity. For example, a scientist observed that some objects were heavier than others. He collected more data and looked for regularity until he found a pattern of direct relationship between volume and weight. His findings showed that, with this particular substance, if he increased its volume he increased its weight. Now, his imagination apparently produced a union or synthesis that some unit weight had some unit volume, and that this was a fundamental property of this substance. Proper experiences in science, properly introduced, can allow the imagination to expand and thus incorporate the new relationship of weight and volume into the individual's mental framework.

In order to facilitate this expansion of productive imagination most effectively, the teacher must recognize that science and science teaching needs to be approached in a fashion that will allow it to be realized. This will be treated under Goal Number Six.

Goal Number Five: To Foster and Advance the Individual's Attitude of Friendly Skepticism Toward Outside Influences, Scientific and Nonscientific

The age of now is filled with many conveniences and, in some cases, unwanted complexities that have been brought to fulfillment by science and its associated technology. A climate of friendly skepticism—possibly healthy conservatism—appears to have merit as a public attitude. Quoting Roberts, "To live comfortably with science it is necessary to live with a dynamically changing system of concepts. It is necessary to live with enough conservatism to resist the easy abandonment of concepts, but enough flexibility to be able, when necessary, to switch rather than fight" (14).

The scientific community has long recognized and assumed its responsibilities for dispassionate inquiry; for responsibility to publish its findings such that knowledge becomes the property of all; for the rigorous subjection of its new knowledge to debate an objective criticism. Scientists, when they are engaged in science, are rational people. As they search for clues and answers, they reject these clues or answers unless they find support through empirical data. They cannot allow prejudice or bigotry to influence their results. Scientists were not born this way; they took a long time learning.

Some of these characteristics of the scientific community should be carried

into nonscientific areas by the insistence of scientists and by the teaching of science to our youth. As the pressures of social, economical, political, educational . . . problems continue to increase, the need to attack these problems with controlled emotion and rationality also increases. In this age of fantastic mobility, extremely efficient communication, energy sources that can be ultimately destructive, and overpopulation bring with them problems that simply cannot be ignored, because they will not go away. It seems rather irrational to leave attempts for solution of these problems to chance. It is also evident that many of our problems will be attacked emotionally; however, these solutions can be dangerous and at best short-lived. Lawson states,

> It is probable that the transfer of rational behavior from science to nonscientific areas will not occur solely on the basis of learning science, but it is certain that such transfer will not occur if children have no contact with science at all (10).

Science must not and, to this writer, will not eliminate the "humanness" from our culture. However, if science is to contribute to the management of our human problems, the climate of the scientific community needs to be transmitted to more people. In a climate where things are not taken for granted, there is an aversion to superstition; freedom of inquiry is first and foremost.

Goal Number Six: To Foster and Advance the Individual's Realization That Science is a Human and Knowable Endeavor

At one time, science was thought to be a static, fixed collection of facts or truths about our world that were produced by somewhat peculiar people called scientists. This placed the body of scientific knowledge in a category like a stamp collection, systematically cataloged. The scientist operated something like a camera that takes pictures of what exists. After the pictures are taken, they become natural history. The scientist arranges his natural history in an order that exists in nature and that he can perceive.

If this is science, then the teaching of science can be merely one of relating these natural historical facts and be done with it. However, modern understanding of science rejects this idea and, instead, recognizes that what a scientist (or anyone) observes depends as much on his past experiences and conceptual framework as on what he observes. It recognizes that some ideas are better than others, because they explain or account for the phenomena with more meaning. It also recognizes that these ideas are products of man's invention imposed by him upon the empirical facts of the world. They also represent nothing more than the best approximation he can make at that time. It follows that the more man knows about his world the better approximations he can make, and the more precise his predictions about future events may be.

This leads us to the approach of science teaching. A student seems to be involved in science by any or all of four levels. The first, and least effective, is reading about or being told about science. The second includes teacher-pupil

and pupil-pupil discussions about science. These levels are largely abstract and, especially in the case of elementary students, understanding is limited to the student's ability to understand the printed or spoken word and to the verbal expression of his ideas. The student is involved on a third level, when the teacher or another student conducts a demonstration with science equipment or materials. This is somewhat more effective in communicating ideas about science, except that the noninvolved student usually reacts passively to the demonstration. The fourth level finds the individual confronting the materials and phenomena he is studying. He manipulates the materials, observes, interacts, fails, succeeds, becomes frustrated, but is involved in his own way. His findings are his own and are determined by what he does. Consequently, he at least experiences science firsthand. Here is where he has the best opportunity to realize that science is human and knowable.

Summary

The study of philosophy regarding science and science education suggests that there are many implications for teachers if we are to impart this endeavor to our youth. The teacher must spend a great deal of time listening to students and observing their work on the highest level of scientific involvement. The teacher needs to develop his ability to ask questions which intensify the students' interest. The teacher must accept the students' response as being worthy, and not stifle it because it is not the specific response of which the teacher is thinking. He must develop the ability and desire to accept students' answers as evidence of their observation or understanding of the situation being examined. This means that the prospective teacher should spend his preservice training in situations that develop these characteristics. The teacher without these preservice experiences will not develop them upon accepting his first teaching position. It has been said many times that "you can't teach something you don't know" and by the same token one can hardly expect pupils to learn attitudes that their teachers don't have.

In our science classes we must insist that the instructional materials and teaching strategies reflect completely the spirit of the discipline that we teach. By that it is meant that science education must embody continual inquiry, free investigation, and the allowance of students to be responsible for their own progress. They deserve a chance to succeed, to fail, to blindly stumble around and finally to find the necessary impetus to regroup and proceed forward or backward again. This is the way education is and we ought not pretend otherwise.

There is no one way to develop scientific literacy. However, education needs to provide the opportunity to look continually for the ways so that the nature of the scientific enterprise and its place in contemporary society may be properly understood.

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