SCIENCE AS A SYSTEM OF INQUIRY – FOCUS FOR A GENERAL EDUCATION PROGRAM

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CHAPTER I
INTRODUCTION

The Need for the Study

Throughout the recent history of higher education in the United States, there has existed a question as to the instruction in the natural sciences which should be required for all college students. The general requirements of an institution may include specific course offerings which are required for graduation from the institution; they may include alternatives from which a student may choose a number of courses; or, there may be some program for distribution of electives outside the student's major area of specialization. The statements of such requirements which appear in college catalogs, and the changes which occur through a series of publications of any one institution, make it impossible to set forth any normative statement of general requirements for American colleges.

In most cases, the faculty and administration of an institution, in framing whatever statement of general requirements is current in its publications, will formulate a rationale for that statement based on some concept of liberal education or general education.

The concept of liberal education as "education primarily for culture by means of the liberal arts,"¹ has strongly affected the design

of programs of undergraduate education. In such a program, each of the scholarly disciplines is supposed to make its contribution to the development of the scholar. As long as the number of disciplines was relatively few and the scope of knowledge dealt with in each was limited, as in classical scholasticism, such programs were generally satisfactory.

By the beginning of the twentieth century, three forces had developed which raised doubts as to the validity of these classical scholastic programs.

1. The growth of knowledge produced criticism of the classical scholastic truths. This was particularly the case in the natural sciences. In the classical tradition, the study of the natural environment served the disciplines of philosophy and mathematics as a source of evidence. The sciences were the children of philosophy. But through the three hundred years from Bacon to Einstein, the children outgrew their parent. Physics, chemistry, botany, and zoology became disciplines in their own right.

Other areas of inquiry also developed independence. Psychology, political science, sociology, economics, anthropology, and a variety of specialized fields in literature, art, and music demanded recognition as disciplines. Each new chair in the university made its claim as a liberal art to establish its place in the liberal education of the college student.

2. Change in the concept of learning brought into question the educational nature of the disciplines. The intellectual faculties as
powers to be strengthened by rigorous exercise gave way to a functional concept of learning as the result of interaction through the medium of knowledge. From this new view, scholasticism appears as a screening device to separate those who can learn in spite of the system and those who need guidance to a liberal education.

3. Changes in the purpose of college education raised further doubts as to the validity of the concept of liberal education as cultural preparation. With the advent of the land-grant college in the latter half of the nineteenth century, the undergraduate program became something more than training for scholarly professional study. The distinction between college and university became confused. In a higher education program devoted to the development of agriculture and the mechanical arts, education primarily for culture by means of the liberal arts lost much of its appeal.

As a result of these forces, the center of attention in the concept of liberal education has shifted from the cultural education provided through study of the learned disciplines to the freedom of the mind implied in the term itself. This new view of the ancient idea is set forth in the May 1964 issue of Liberal Education, in which Hutchins writes:

The Jacksonian revolution put an end to the Yale faculty's dream of 1828 that the liberally educated few would govern the country while the rest of the population was scrambling for a living. The technological revolution puts an end to the notion that the many can be drained off into working for a living or into schooling that purports to train them to do so. They will be free to be educated to be rulers, too.
In the simple days of Jackson perhaps it did not matter much whether they were or not. Now one can seriously raise the question whether American democracy will turn out, like the Athenian, to be a brief efflorescence of a temporary combination of favorable circumstances. One can seriously ask whether in a country like this, democracy is any longer possible. I believe it is. But I believe it is only if we at once resume the dialogue about the institutions, the programs and the methods by which the mind of every man may be set free.2

The concept of general education is to a very great extent the product of "The College of Chicago." The history of general education up to the 1940's is the history of the College of The University of Chicago from its founding under William Rainey Harper and of the men such as Vincent, Angell, Boucher, Wilkins, and Faust who directed its development and carried its message abroad.3

The Journal of General Education began publication in October 1946, and has since served as the principal medium for the development and criticism of the concept of general education. McGrath, in the initial editorial, characterized The General Education Movement in eight statements:

General education is that which prepares the young for the common life of their time and their kind . . .
General education is not concerned with the esoteric and highly specialized knowledge of the scholar . . .
The salient feature of this movement is a revolt against specialization . . .


Another characteristic of the general education movement is its reaction against vocationalism...
The reaction against specialism and vocationalism is accompanied by an effort to integrate the subject matter of related disciplines...

To increase the scope of education and to combat specialism a larger proportion of the total college program is being prescribed...

Exponents of general education believe that education should be more clearly related to the vital needs and problems of human beings...

And lastly, those interested in general education seek an improvement in the teaching of the general student.4

But the concept of general education reflected in such statements as these has undergone modification. By 1962 we find Hamilton saying:

If general education stands uniformly for anything, it stands for the principle that there are certain competences, certain areas of knowledge, with which every educated man or woman should be familiar, and that these areas are susceptible of broad definition. Having made this reasonable assumption, however, and having attempted to export it to the alien camp of professionalism and specialism, the movement has been forced to look back upon itself only to discover that its own seamless robes have been somewhat shredded. Thus, having itself had little success in arriving at a shared notion of what these common educational experiences ought to be, it was manifestly impossible that it should successfully convert the great unwashed. This realization, I think, has been largely responsible for the subsequent search for objectives or outcomes that might be shared by all advocates of general education -- not experiences, not areas of knowledge, certainly not courses, but objectives and outcomes.5

The problem is clearly present, whether it is seen as resumption of "the dialogue about the institutions, the programs and the methods by which the mind of every man may be set free," or the "search for objectives or outcomes that might be shared by all advocates of general education."


To give each student the instruction he needs, we must devise a general program for all students which unifies knowledge in a meaningful way, has intellectual integrity, and which relates the student's educational experience to that which he receives from other sources, has intellectual continuity.

The Purpose of the Study

In this work we propose to develop, rationally, a program for science in general education having integrity and continuity; a program which will provide learning experiences to which each person fully matriculated in an institution of higher education should be exposed; a program which will provide meaningful unity within the conventional knowledge of man; and which will relate the educational experiences of the student within the school to the experiences derived from other sources.

It may be that we undertake too great a task. An associate of the writer recently made a statement to the effect that there is no scientific way by which we may reach a conclusion as to either the general or specific nature of such requirements. If this is true, the word rationally should be stricken from our opening sentence. It is the feeling of the writer, however, that the gentleman's statement indicates a lack of understanding of the basic nature of scientific thought. In situations where this point of view prevails it is probable that there is a serious weakness in the program of liberal education which we must strive, rationally, to overcome.
We intend to set forth a definitive statement of the purpose of general education, and of the function of science in the program of general education at the college level, and to propose means by which this function may be implemented.

We will present the materials and describe the activities of a course (40-161: Introduction to the Natural Sciences) in the present program at Inter American University of Puerto Rico, and illustrate how, in design at least, it can serve as the basis for an integral, continuous program for science in general education at the college level.
CHAPTER II
THE FUNCTION OF SCIENCE IN GENERAL EDUCATION

The Purpose of General Education

We might begin our consideration of the purpose of general education (the planned learning experiences to which every person fully matriculated in an institution will be exposed) with a consideration of theories of knowledge as presented by Dewey.¹ On the basis of a metaphysical dualism of particular knowledge versus universal knowledge, an epistemological distinction may be made between sensationalism, the coming to know through sense experience with bare facts; and rationalism, the coming to know through the development of bare relations by higher mental processes. Dewey concludes:

In real knowledge, there is a particularizing and a generalizing function working together. So far as a situation is confused, it has to be cleared up; it has to be resolved into details, as sharply defined as possible. Specialized facts and qualities constitute the elements of the problem to be dealt with, and it is through our sense organs that they are specified. As setting forth the problem, they may well be termed particulars, for they are fragmentary. Since our task is to discover their connections and to recombine them, for us at the time they are partial. They are to be given meaning; hence, just as they stand, they lack it. Anything which is to be known, whose meaning has still to be made out, offers itself as a particular. But what is already known, if it has been worked over with a view of making it applicable to intellectually mastering new particulars, is general in function. Its function of introducing connection into what is otherwise unconnected

constitutes its generality. Any fact is general if we use it to give meaning to the elements of a new experience.²

From this definition of general knowledge, it is not unreasonable that we might reach the conclusion of the Progressive Education Association that,

The purpose of general education is to meet the needs of individuals in the basic aspects of living in such way as to provide the fullest possible realization of personal potentialities and the most effective participation in a democratic society.³

This statement of purpose may be valid, but if it is to be functional in the design of programs for general education, it must provide a basis on which we may define the objectives of the program and, to some extent at least, evaluate the degree of achievement of these objectives. In practice, statements of purpose such as this have served as a basis for post factum rationalization of various, widely diverse, statements of immediate objectives rather than the basis for deriving such objectives.

More specific is the statement by Prescott.

In my opinion the objectives of general education should be: (1) the development of clear thinking leading to intelligent action; (2) the development of clear, convincing, and persuasive expression as the medium for expressing thought; (3) the development of an imagination sensitive to the effects of literature, music, and the plastic arts; (4) the knowledge and understanding of the history of the past and the environment of the present in those respects that vitally affect intelligent activity in our present-day world.

²Ibid., p. 399.

These four aims and in this order should determine the prescribed core of the curriculum through the entire eight years. (Grades 7-12). 4

From such a statement of purpose as this, we may be able to define the cognitive and affective objectives for a program of general education.

Faust has given us a statement which is in essential agreement with these, "General education appears from this point of view to be preparation of youth for dealing with personal and political problems with which all men in a democratic society are confronted." 5 With further elaboration, a functional basis for defining objectives is provided.

The development of the capacity to form sound judgments will therefore involve three things: the refinement of logical and methodological processes in relation to subject matters to which they are appropriate; practice in dealing with particular problems; and proper use of our heritage of discussion of knowledge. Acquaintance with the last alone may make a man an encyclopedia; familiarity with method alone may make him a skillful intellectual chess player. The three properly coordinated may make him wise. 6

From these statements, and from the writing in the Thirty-eighth and Fifty-first Yearbooks of the National Society for the Study of


6Ibid., p. 63.
Education\(^7\) and the works of Mayhew and others,\(^8\) we can abstract a three-fold statement of purpose: (1) the development of the skills and techniques of inquiry by which knowledge in the various disciplines is derived, verified, and elaborated; (2) refinement and continued development of the skills of expression necessary for effective communication of this knowledge; and (3) the achievement of adequate subject matter competence in particular disciplines so that these preceding two purposes may be effectively implemented.

This statement of purpose can serve as the basis for a functional definition of immediate objectives for the general education program. There may be disagreement as to the hierarchical order of these three aspects of purpose. There would certainly be disagreement as to the breadth and depth of subject matter competence required for the third. We feel, however, that from this base, a general education program can be developed which will have integrity and continuity.


The Function of Science in General Education

From a review of the literature, we can also develop a concise statement of the function of science in general education. Rogers writes:

In general education, we need not start the training of professional scientists (that can be done much faster once the vocation is chosen); we need not try to equip everyone with a lot of scientific knowledge (that can be stored in books or left to the professionals); but we need to give an understanding of science and its contributions to the intellectual, spiritual, and physical aspects of our lives.9

Conant indicates the nature of this understanding of science:

Being well informed about science is not the same as understanding science, though the two propositions are not antithetical. What is needed are methods, for imparting some knowledge of the Tactics and Strategy of Science to those who are not scientists. Not that one can hope by any short-cut method to produce in a layman's mind that same instinctive reaction toward scientific problems that is the hallmark of an investigator, but enough can be accomplished, I dare hope, to bridge the gap to some degree between those who understand science because science is their profession and those who have only studied the results of scientific inquiry -- in short the layman.10

This heightening of interest in inquiry as a process, in understanding science, and in the Tactics and Strategy of Science, can be traced through the three Yearbooks of the National Society for the Study of Education devoted to science teaching. In the earliest of these three volumes, Powers writes,

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In a program of general (or liberal) education those truths which are the foundation of our social order and those methods which may be effectively used to reveal truth must be given prominence in the curriculum.

In this analysis, values are considered under two general headings: (1) those values which arise from the direct use of facts, principles, and generalizations of science in everyday life, and (2) those values which are secured concomitantly from the study of natural sciences through forming generalizations respecting methods and through formulating generalizations from which scientific attitudes may reasonably be expected to develop.11

In the second of these volumes, we find this statement set off in italics:

Science is today on a place of high significance and importance. It is no longer, if indeed it ever was, a mysterious and occult hocus pocus to be known only to the select few. It touches, influences, and molds the lives of every living thing. Science teachers have a great opportunity and responsibility to make a large contribution to the welfare and advancement of humanity. The intellectual aspects of this responsibility are at least coequal in importance with the material. Science is a great social force as well as a method of investigation. The understanding and acceptance of these facts and this point of view and their implementation in practice will, more than anything else, make science teaching what it can and should be.12

In the most recent of the three volumes, quotations from Nagel, Rogers, and Schwab are cited as indicative of the trend toward agreement on the objectives of general courses in science. The three quotations demand in turn greater consideration of, "the operation of scientific method," "sympathetic understanding of science and the way scientific


work is done," and recognition of the nature and function of scientific theory.13

We see here the advancement of scientific inquiry and methodology from the status of concomitant learning, through a phase of coequal importance to the central theme of the definition of the function of science in general education. A similar tendency may be seen in the discussion of particular programs in the two volumes entitled Science in General Education published in 1948 and in 1960.14

In terms of our statement of threefold purpose of general education, we may say that the particular function of science is: (1) to present a well-defined system of inquiry as an example of, and model for, structured inquiry in all areas of knowledge; (2) to provide examples of, and experience with, the forms of expression and style of writing used in science reporting; and (3) to provide opportunity for achievement of a minimal level of subject matter competence in the conventional knowledge of man's external environment.

On the basis of personal conviction, supported by the rationale which will be presented in this work, we would set this minimal level of subject matter competence so as to include demonstrable understanding, in depth, of at least one relatively narrow segment of the conventional


knowledge from both the biological sciences and the physical sciences. As examples, we would suggest chemical structure and the nature of chemical change, the physics of the motion of particles and wave motion, the history and structure of the earth's crust, the ecology of the world biome, human physiology and genetics, or the genetic evolution of species. The definition of any one segment would be left to the scholars in the appropriate discipline.

This knowledge should be supplemented with an overview of the broad spectrum of conventional knowledge represented in such universal principles as evolution through change and selection, forces in dynamic equilibrium, multiple causation, and conservation of essentials.

Summary

We have defined the general education program of an institution, as those planned experiences to which all pupils will be exposed. In this chapter we have derived, from selected authoritative sources, a statement of the purpose of general education: (1) the development of the skills and techniques of inquiry by which knowledge in the various disciplines is derived, verified, and elaborated; (2) refinement and continued development of the skills of expression necessary for the effective communication of this knowledge; and (3) the achievement of adequate subject matter competence in particular disciplines so that the preceding two purposes may be effectively implemented.

We have set forth, as the function of the natural sciences in achieving this purpose: (1) to present a well-defined system of inquiry
as an example of, and model for, structured inquiry in all areas of knowledge; (2) to provide examples of, and experience with, the forms of expression and style of writing used in science reporting; and (3) to provide opportunity for achievement of a minimal level of subject matter competence in the conventional knowledge of man's external environment.

In the succeeding chapters of this work, we will develop a system of thought within which the purpose and function thus defined is reasonable. We will review some techniques by which the study of inquiry has been used for the teaching of conventional knowledge of science and to extend science teaching beyond the achievement of this knowledge. We will describe a course which has been developed to use knowledge about the process of inquiry and show that this course can contribute meaningfully to the fulfillment of the defined function of science in general education.
CHAPTER III
THE PEDAGOGICAL RATIONALE

Introduction

Throughout the literature related to both science teaching and general education there exists a confusion of concepts and terminology which makes communication difficult. While it is often possible to bring together a variety of statements which may be made to appear to be in agreement (as we have done in the previous chapter of this work), the systems of thought in which these various statements have been formulated are often so basically different or so difficult to define as to make consistent, constructive criticism very nearly impossible.

In order to invite the type of criticism which is essential if we are to move forward in the development of integral continuous programs of general education, we would set forth a concise, definitive statement of the fundamental assumptions and definitions which form the basis of our system of thought.

To illustrate the positive value of such a statement, an analog from current writing in the history and philosophy of science might be used.¹ Contrary to many opinions, Aristotle was neither blind to

reality nor less than brilliant when he developed his discussion of
motion. If one considers all motion as occurring against a resistance,
covering a finite distance in a finite time, the generalizations about
motion which were made by Aristotle are eminently reasonable and highly
significant. The ratios and proportions set forth are essentially valid.
Confusion developed when examples of motion which did not fit the
paradigm were rationalized in terms of these generalizations.

Galileo reduced the confusion by altering the paradigm. Con­
tinuous motion (or lack of motion) is natural, changes in motion require
an impelling force on the body or resistance to its motion. A modified
set of relationships, a different system of thought developed which
explained away the confusion. But new observations created new con­
fusion. Newton and Einstein, in turn, made further modification of the
paradigm. Motion is now dealt with in terms of a time-affected obser­
vation of instantaneous velocity over an infinitesimal distance against
no resistance. 2

The rationality of the explanation depends on the nature of the
paradigm. An explanation or a derivation is, or is not, rational
within a system of thought, and criticism of the rationale should be
made within that system.

2 There arises the interesting question as to which paradigm is
more "real," less "metaphysical." Aristotle is often accused of having
neglected empirical reality. Is motion against no resistance over an
infinitesimal distance at an instantaneous velocity more real?
A Paradigm for Pedagogical Theory

In our system of thought, "Education" is education, an undefined term. Change in behavior is the result of education. Learning is the process by which an individual obtains education. Each and every individual, at each and every moment in time, has an education. An educational experience is any circumstance which produces learning which results in a change in behavior. The education which any individual has at any moment in his life is the result of the whole of his accumulated educational experience, limited by his developmental capacity for education and his inherited potential for education.

Education occurs as a result of activity. Most education occurs incidentally to the purpose of the activity from which it results. Education may be planned as a concomitant result of activity whose principal purpose is other than education. Activities whose principal purpose is the derivation of education might be termed planned educational endeavor, or, more simply, schooling.

The school is a social institution set up to provide activities whose principal purpose is the derivation of education, the enhancement

3The writer is inordinately fond of this statement of Keyser, "If he [anyone] contends, as sometimes he will contend, that he defined all his terms and proved all his propositions, then either he is a performer of logical miracles or he is an ass; and, as you know, logical miracles are impossible." Casius J. Keyser, Mathematical Philosophy, New York: E. P. Dutton, 1922. p. 152.
of learning, the bringing about of certain changes in behavior. The conventional knowledge related to the process of schooling, the information, concepts, and conceptual schemes which provide the basis for planned educational endeavor which are commonly called "theory and practice of education," we would call the knowledge of the intellectual discipline of pedagogy.

Our paradigm for pedagogical theory might be summarized in three postulates:

1. Education is universal as to source and distribution. The function of pedagogy is to provide educational experience which will integrate, supplement, and elaborate the educational experience of the individual derived through other activities, so that the total education of the individual will fit him for productive participation in the society.

2. Analysis of the purposes and objectives of pedagogical programs will depend on: (a) the definition of productive participation by the individual which is current in the society, (b) the nature and extent of the educational experience which the individual derives through other activities, and (c) the present body of conventional knowledge available in the society.

3. The ultimate goal of schooling in our democratic society is to assure, to as full an extent as possible, that every person have an

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The writer does not wish to add to the confusion through the re-introduction of the term pedagogy. However, since our paradigm requires a distinction between education and schooling the word "pedagogy" in its various forms will be used rather than the word "education" typical of the literature in the field.
opportunity to obtain an education which will result in intelligent behavior, that is, behavior which is appropriate to the situation, rewarding to the individual, and acceptable to the society.

Analysis of the Objectives of Pedagogy

One cannot discuss the objectives of pedagogy (education, if you prefer) without considering the work of the Committee of College and University Examiners and the reports of this committee. 5

This group set out to construct a theoretical framework to facilitate communication among examiners. In order to obtain definition of educational objectives on which to base the building of curricula and tests, and to serve as a starting point for educational research, the committee set up a system for classifying the goals of the pedagogical process, a Taxonomy of Educational Objectives. The system of the Taxonomy is structured from the domains of cognitive, affective, and psychomotor objectives. Within each domain are categories of goals under which operationally defined, immediate objectives of pedagogical activities may be classified.

The classification of objectives into cognitive, affective and psychomotor domains is orderly and sensible. The categories in the affective domain have been reasonably defined at a level which is

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sufficiently operational to be useful in evaluation of the effectiveness of a pedagogical program. The classification and definition of goals in the cognitive domain has unquestionably produced a beneficial effect upon the whole process of design and evaluation of pedagogical programs.

We will use this system of classification of goals in our proposal for evaluation of student achievement. However, in establishing the rationale for the program, a different type of statement of objectives would be more productive. We would agree with the fear expressed in the committee, "that the taxonomy might lead to fragmentation and atomization of educational purposes such that the parts and pieces finally placed into the classification might be very different from the more complete objective with which one started." 6

We believe it would be productive to define another dimension to the analysis of objectives; a "vertical" dimension running from the ultimate objective of intelligent behavior which we have postulated (postulate 3, page 20) to the operationally defined, immediate objectives represented in the Taxonomy.

Somewhat "below" the ultimate objective we might define a level of specificity at which we can place such statements of objectives as these: from Dewey, "The criterion of the value of school education is the extent in which it creates a desire for continued growth and supplies means for making the desire effective in fact." 7 from Bestor, "...

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schools exist to teach something and this something is the power to think. 8 from Cox, "... it (Schooling) is rather the stimulation of the desire to learn, a readiness to seek one's own answers to his questions, and the habit of success." 9 from the Rockefeller Report on Education, "One of our greatest strengths as a people has been our flexibility and adaptability under successive waves of change that marked our history. ... It is for this reason that we should educate our young people to meet an unknown need rather than to prepare them for needs already identified." 10 from Admiral Rickover, "He (the citizen of a democratic country) needs to learn how to lead a good life no less than an efficient one. Above all he must be taught how to use his mind independently so that he may be a free man." 11 from Dr. Handlin, "... The high school cannot endow its students with everything they ought to know. It can only equip them to get what they need as they come to recognize the need for it." 12 and from Provost Klotsche, "Our need to know in the face of the explosion of new knowledge should, then become one of our greatest concerns ... Adaptability to change is probably


12 Oscar Handlin, "Live Students and Dead Education," The Atlantic, 208: 29-34, (September 1961), 32.
the greatest challenge that faces education today...\(^\text{13}\)

It might be said that these statements define objectives of pedagogy at a level below the ultimate. At this level of intellectual quality the objectives of the development of desire to learn or the desire for continued growth, flexibility and adaptability, and independent use of the mind are indicated in these statements. We would add to the objectives at this level the development of intellectual curiosity and the refinement of creativity.

These objectives of intellectual quality involve all of education. If the distinction between education and pedagogy which our paradigm calls for (postulate 1, page 20) is recognized, objectives may be defined at another level. This we would call the level of pedagogic function. At this level would be placed such objectives as the preservation of creativity, the development of skills of inquiry, commitment to an acceptable value system, achievement of subject matter competence, and achievement of vocational competence. It is through the accomplishment of these objectives that the school will serve to integrate, supplement, and elaborate the educational experiences of the pupil so as to accomplish the objectives at the level of intellectual quality and thus develop intelligent behavior.

At least one other level exists at which objectives have been defined. At this level would be such goals as those from the Cardinal Principles of Secondary Education: “1. Health. 2. Command of

fundamental processes. 3. Worthy home-membership. 4. Vocation.
5. Citizenship. 6. Worthy use of leisure. 7. Ethical character. Whether this level of personal quality should be the special province of the school (and thus lie below that of pedagogical function), or should be shared with other cultural institutions and educational forces (and thus lie above that level), may be open to debate.

Finally, there is the level at which our immediate objectives should be defined in operational terms as indicated in the Taxonomy. This we would call the level of operational evaluation.

Figure 1 presents a diagram of the suggested ideational model. The tracing of the web of relationship which exists among objectives at the various levels will not be attempted here. Certainly there is relationship. Our task requires the identification of those objectives from this analysis which are significant to the function of science in general education at the college level.

Identification of Pedagogical Tasks

According to this ideational model for discussion of schooling, this theory of pedagogy, the ultimate goal is the development of intelligent behavior. In order to achieve this goal, the school must be designed and programed to provide experiences which will integrate, supplement and elaborate the education which the individual derives from other sources.

Figure 1

Analysis of Educational Objectives: A Vertical Dimension

The Ultimate Objective of Intelligent Behavior

<table>
<thead>
<tr>
<th>The Level of Intellectual Quality</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Creativity</td>
<td>Desire to learn and grow</td>
</tr>
<tr>
<td>Flexibility and Adaptability.</td>
<td>Independent use of the Mind.</td>
</tr>
<tr>
<td>Intellectual Curiosity</td>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>The Level of Personal Quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Health</td>
</tr>
<tr>
<td>Command of Fundamental Processes.</td>
</tr>
<tr>
<td>Worthy Home-membership.</td>
</tr>
<tr>
<td>Vocation.</td>
</tr>
<tr>
<td>Citizenship.</td>
</tr>
<tr>
<td>Worthy use of Leisure.</td>
</tr>
<tr>
<td>Ethical Character.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>The Level of Pedagogic Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preservation</td>
</tr>
<tr>
<td>Development of Skills of Inquiry.</td>
</tr>
<tr>
<td>Commitment to an Acceptable Value System.</td>
</tr>
<tr>
<td>Achievement of Subject Matter Competence.</td>
</tr>
<tr>
<td>Achievement of Vocational Competence.</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>The Level of Operational Evaluation</th>
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<tbody>
<tr>
<td>Operationally defined objectives of the Taxonomy</td>
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</tbody>
</table>

Each individual will spend something less than five percent of the probable total of his waking hours in school. During the other ninety-five percent of his time (five years before entering, thirty-five years after leaving, and slightly more than half his time while enrolled), other agencies will be providing him with educational experiences. For this alloted time to be used effectively, the activities provided by the school must be efficiently organized and the pedagogical tasks carefully allocated.

The pedagogical tasks to be assigned should be defined by our analysis of educational objectives. But at what level? Certainly the ultimate objective of intelligent behavior is too general to serve as the basis for such an assignment. This is everybody's job. At the other extreme, at the level of operational evaluation, the objectives are too specific. Each person involved in the pedagogical undertaking will have his own definition of the immediate objectives appropriate to his effort.

One of the intermediate levels of objectives must be used. Our purpose is best served by the objectives at the level of pedagogic function. At this level we have placed the pedagogical objectives of: (1) preservation of creativity; (2) commitment to an acceptable value system; (3) development of skills of inquiry; (4) achievement of subject matter competence; and (5) achievement of vocational competence. If these concepts are to serve as the basis for the identification of pedagogical tasks, there must be more detailed delineation.

In the analysis of creativity there have been identified several characteristics of creative persons which seem to be adversely affected
by typical school experiences.\textsuperscript{15} We would say, that to meet the objec-
tive of the preservation of creativity, the school must strive to: (a) maintain the child's openness to experience throughout the school program, (b) structure activities which will allow and encourage freedom of expression, (c) encourage and reward divergent thinking, and (d) make provision for flexibility in the utilization of ideas.

Analysis of the pedagogical objective of commitment to an accept-
able value system might start from the distinction between moral ideas and ideas about moral action stressed by Dewey.\textsuperscript{16} A sound education will provide for both the development of the former and the derivation of the latter.

It is in this area of moral education that the continuity of edu-
cation and pedagogy (as we have defined these terms) is most marked. For this reason it is most difficult to distinguish the specific function of the school. Dewey does identify the pedagogical resources: "(1) the life of the school as a social institution in itself; (2) methods of learning and of doing work; and (3) the school studies or curriculum."\textsuperscript{17}

\textsuperscript{15}\textit{Creativity of Gifted and Talented Children}, New York: Bureau of Publication, Teachers College, Columbia University, 1959. Interdiscri-

\textsuperscript{16}John Dewey, \textit{Moral Principles in Education}, Cambridge, Massachu-

\textsuperscript{17}\textit{Ibid.}, p. 43.
While much of the recent literature in the areas of teaching morals and values has been centered on the teaching of spiritual, social, and political ideals, we can abstract from these writings the pedagogical tasks of guiding the pupil in the development of: (a) an understanding of the value system of the society, (b) sensitivity to the needs of others, (c) personal identification within the society, and (d) acceptance of responsibility for one's acts. We would add to these a fifth, (e) intellectual honesty.

Our third objective at the level of pedagogical function is the development of skills of inquiry. Here the task of the school is more easily identified. Here the school has been more effective than in the preservation of creativity. Here the work of the school is more easily distinguished from that of the rest of education than in the function of commitment to an acceptable value system.

The tasks of the school in fulfilling its function of the development of skills of inquiry are the development and refinement of skills needed for: (1) obtaining information, skills of observation and record keeping, and skills of reading; (2) interpretation of information, skills

of analysis and conceptual thought, use of abstraction and analogy, logical and mathematical interpretation and criticism, and (3) exposition, skills of writing and literal expression, of speaking and verbal expression, of logic and mathematical expression.

The final objectives related to subject matter competence and vocational competence are complicated by the extent and diversity of knowledge and the applications of knowledge which are involved. Definition of the pedagogical tasks involved in the achievement of vocational competence is best left to the authorities within the particular vocations. Subject matter competence requires that experiences be planned so that essential information be supplied to the pupil in a manner which will result in the ability to recall facts, relate the facts to broad general ideas, and apply these facts and ideas in new situations.

In order to achieve subject matter competence, the pupil must be led to develop a functional vocabulary of conventional terminology. The words and symbols must represent, for him, a rational structure within which elements of information are fitted together, as concepts, into conceptual schemes and general propositions. The information which the pupil gains from his study of human history and culture must form a network of ideas and relationships into which he can fit new information gained from further study and observation, and from which he can abstract what is needed for effective behavior in each new situation.

There is no question that this is a proper pedagogical function. Without subject matter competence, creativity is meaningless; freedom of expression is impossible without ideas from which free expression may be
formed. Commitment to an acceptable value system requires ideas about moral action from which to judge the morality of ideas. The skills of inquiry require subject matter with which to carry on inquiry and from which to formulate questions worthy of inquiry. The problem is the identification of the essential information.

It is the conviction of the writer, that except in those areas where accepted authority can stipulate the subject matter necessary for fulfillment of that pedagogical objective, it is impossible to identify the specific items of information (the subject matter) which the pupil will need to fulfill the ultimate objective of intelligent behavior during his lifetime. We believe that if the school effectively fulfills the pedagogical functions assigned to it, the pupil will be able and willing to identify and develop competence in that subject matter which is essential to him. Therefore, the particular subject matter involved in the achievement of subject matter competence is incidental to the other pedagogical functions.

Accepted vocational authority may stipulate the subject matter competence required in that vocation. The mores of the society define the subject matter competence required for commitment to an acceptable value system. For the fulfillment of the other elements of pedagogical function, subject matter should be selected which will most obviously contribute to that function. If there seem to be alternatives, that subject matter which is of most immediate interest to the student should be utilized.
Allocation of Pedagogical Tasks

We have identified a set of pedagogical tasks. It is now necessary that these tasks be allocated, that we stipulate who shall be responsible for what.

There are three bases on which the pedagogical enterprise is commonly divided: (1) division on the basis of which pupils shall be involved, into general and non-general; (2) division on the basis of chronological order into elementary school, secondary school, and higher education; and (3) division on the basis of the academic disciplines involved, into the arts, the humanities, the social and behavioral sciences, and the natural sciences. On each basis further subdivision is possible, but this will serve our purpose at the moment.

On the basis of which pupils shall be involved, we have defined general education as those pedagogical experiences to which all pupils will be exposed. Those experiences which are appropriate to specific groups or individuals only are non-general. These include experiences appropriate for the achievement of competence in particular vocations. This we call vocational education. Experiences appropriate to individuals by virtue of exceptional inherited potential or developmental capacity for education we call special education.

Those experiences which are appropriate for the achievement of vocational competence regardless of the vocation, those experiences which are not inappropriate to the atypical pupil, and those experiences planned for fulfillment of the functions other than vocational competence should be included in general education. Except where it can be shown that for
particular individuals, equivalent experiences can be provided more effectively or more efficiently as non-general education, the provision of all such experiences should be in the general education program.

In assigning tasks to the chronological divisions of the pedagogical enterprise, we must consider the developmental capacity of the pupil in the various units. On the basis of studies of child development and perceptual psychology, we would assign to the elementary school the principal responsibility for the functions of the preservation of creativity and commitment to an acceptable value system. It is at this age (five through eleven years) that the essential personal qualities implied in these functions are developing.

We would also assign to this unit the elementary tasks related to the development of skills of inquiry, particularly the development of skills of observation, of reading, of writing, and those concepts of mathematics involved in numerical calculation. Of course, these pedagogical functions should be served by experiences in the higher chronological divisions as well. But the principal responsibility rests with the elementary school.

The elementary school should be concerned with the achievement of subject matter competence only in so far as subject matter serves as the medium for meeting its assigned tasks. Subject matter which excites the interest and curiosity of the pupils, which leads him to the development of an extended structure of conceptual thought, an expanding vocabulary of conventional knowledge, should be utilized.

Such subject matter should be used in a way which will provide the
self-assurance and intellectual independence necessary for creativity. Subject matter which provides the information necessary for moral decisions and models for moral behavior should also be used. A diversity of materials through which skills of observation, of reading, of writing, and of mathematical operation may be developed, should be provided.

Subject matter from each of the disciplines provides material which must be used if the assigned tasks are to be fulfilled. We would stress, however, that achievement of subject matter competence is the medium through which the assigned tasks may be carried out, not the end of pedagogy at the elementary level. With the possible exception of specific requirements for subject matter competence in mathematical operations, language vocabulary, and grammatical facility, requirements for subject matter competence should be determined by the needs of the other pedagogical functions.

In the secondary school the principal functions to be served are the development of skills of inquiry, commitment to an acceptable value system, and achievement of vocational competence. Those tasks involved in achieving vocational competence appropriate to the age group and common to the wide range of vocations should be included in the program of general education. Those pedagogical tasks required in preparation for vocational education, in particular vocations, outside the school or in higher education should make up a significant portion of the activities in this division.

Of particular interest to this work is the assignment of tasks at the secondary level for the development of skills of inquiry. The pupil entering the secondary school will have a reasonable facility in reading,
writing and arithmetic. The task of the secondary school is to extend and refine the skills of obtaining information, to begin the development of skills of interpretation of information and reflective thinking, and give extended practice in exposition in each of the areas of the disciplines.

The requirement in subject matter competence may be more specific at this level. However, the definition of these specific requirements should be demonstrably related to the tasks of general education, or should be restricted to programs of vocational or special education.

If the tasks assigned to these lower chronological units has been reasonably fulfilled, it can be assumed that a pupil entering the college level of the pedagogical enterprise has; (1) reached a level of facility in reading, writing, and mathematical operation which will allow him to profitably undertake serious study of the structure and substance of the conventional knowledge of the human race; (2) from previous schooling and other educational experience achieved a level of subject matter competence in each of the divisions of the disciplines which will make possible effective reading, discussion and exposition in these disciplines; and (3) developed the commitment to scholarship and intellectual integrity which serious study requires. In short, we may reasonably expect a person entering college to be a student.

The principal tasks which remain for the chronological division of higher education are those related to the achievement of vocational competence (for students entering vocations which require college and university education), and further development of the skills of inquiry.
Again we would stress that this assignment of these tasks does not relieve this pedagogical level of all responsibility for other pedagogical functions. Creativity and moral education must be considered in the design of the educational experiences at this level as well as at all other levels.

General education at the college level should be designed to provide continuation of the development and refinement of the skills of inquiry; particularly the skills of interpretation of information, reflective thinking, and exposition. Subject matter should be selected which will most effectively provide for the fulfillment of these tasks. If this subject matter is desirable for the achievement of vocational competence at this level regardless of the particular vocation, efficiency will be increased.

Subject matter and programs of activities which are designed for achievement of vocational competence in particular vocations should be regarded as vocational education, not general education. Experiences and programs designed to prepare pupils as college students should be regarded as special education, not general education.

The design of general education programs at the college level should be centered upon the task of culminating the development of skills of inquiry. The specific subject matter involved should be that which best illustrates the processes by which conventional knowledge is derived, verified and elaborated. It is highly doubtful that any particular body of conventional knowledge is necessary for this end.

What subject matter is utilized should be studied in sufficient depth and by appropriate methods to give the student intellectual
confidence and self-assurance as to his ability to understand and use conventional knowledge. When the student is aware of the intellectual power which the skills of inquiry provide and convinced of his ability to use that power, he will be willing and able to achieve such subject matter competence as he may need independent of pedagogic endeavor.

Summary

We have attempted in this chapter to develop a sound pedagogical rationale for the proposal we are making of a program for general education in science at the college level. This rationale might be summarized in five points:

1. The school does not provide all the education a pupil receives. Its task is to integrate, supplement, and elaborate the education received from other sources.

2. The function of the school may be analyzed into three segments; (a) general education, (b) vocational education, and (c) special education. While it is not possible to define three mutually exclusive, totally exhaustive sets of experiences for these three segments, it should be possible to center the attention on planning for each segment on its particular function.

3. Those functions assigned to general education should be planned and implemented as general education except where it can be shown that equivalent experience can be provided more effectively or more efficiently through vocational education or special education.

4. It is reasonable to assume that a pupil entering college is
adequately prepared for college study. To the extent that he is not, the provision of experiences needed is the function of special education.

5. A college student, reasonably skilled in the techniques of inquiry in the various disciplines, and committed to scholarship and intellectual integrity, will achieve subject matter competence independent of pedagogical endeavor. Therefore, programs of general education at the college level should be centered upon methods of inquiry using such subject matter as will illustrate the processes by which conventional knowledge is derived, verified, and elaborated.
CHAPTER IV
TEACHING THROUGH INQUIRY

Introduction

In the first three chapters of this work we have centered the attention on science as a system of inquiry. We have set forth the claim that the principal function of science in general education at the college level should be the teaching of this system. Inquiry, as an intellectual activity, has been involved in many other pedagogical proposals. The activities program and the problem solving approach to teaching and learning which were so effectively supported by the Progressive Education Association were designed to use the processes of inquiry as a teaching-learning device.

More recently, the curriculum development programs in secondary science, supported by the National Science Foundation, and most of the elementary curriculum development programs in science and mathematics, have been pointed toward this goal. The literature of "discovery learning," "inquiry training," and "understanding science" indicates increasing interest in teaching through the use of activities related to the process of inquiry.

Discovery Learning

Bruner, in his report of the Woods Hole Conference held in
September, 1959, gave the movement its name.

Mastery of the fundamental ideas of a field involves not only grasping of general principles but also the development of an attitude toward learning and inquiry, toward guessing and hunches, toward the possibility of solving problems on one's own . . . To instill such attitudes by teaching requires more than mere presentation of fundamental ideas. Just what it takes to bring off such teaching is something on which a great deal of research is needed, but it would seem that an important ingredient is a sense of excitement about discovery -- discovery of regularities of previously unrecognized relations and similarities between ideas, with a resulting sense of self-confidence in one's abilities.¹

Stokes² has summarized the work leading to, and derived from, the Woods Hole Conference. From extensive study of curricular materials, reports of opinion, and the results of research related to these materials, Stokes states:

The proponents of learning by discovery make six claims for its superiority.
1. It increases intellectual potency and cognitive skills.
2. It possesses intrinsic motivation.
3. It teaches the heuristics of discovery.
4. It aids recall and memory.
5. It makes learning more meaningful.
6. It promotes transfer of learning.³

From the study of reported research in the evaluation of the activities involved in these programs for discovery learning, Stokes concludes:

³Ibid., pp. 148-49.
The results of the evaluation were largely inconclusive. No
definite statement of the superiority of the methods of instruction
for discovery as compared to the methods of instruction which do not
utilize discovery could be made for any of the six criteria.4

In the comparisons of discovery with non-discovery methods on
which this conclusion is based, the instruments were very largely the
achievement tests developed and used to evaluate the degree of concept
attainment. In this respect there is a serious question of efficiency,
"... the method of discovery would be too time-consuming for present-
ing all of what a student must cover..."5

We might ask, what is the value of discovery learning? Foshay
approaches the question in this way:

What can be discovered through the method of discovery? Two
things: one can discover the discipline one is studying; one can
discover one's self as a learner... It contrasts sharply with
the subject-centered approach that we have known. It is not a
new subject-centeredness; to call it subject-centered is to miss
the point. It is centered upon an attempt to teach children to
grasp the intellectual means through which knowledge is dis-
covered, ...6

It is the structure of the discipline and the relationship of that
structure to the learner that the discovery method is supposed to develop.

There are at least four general claims that can be made for
teaching the fundamental structure of a subject, ...

The first is that understanding fundamentals makes a subject
more comprehensible. ...
The second point relates to human memory. Perhaps the most basic thing that can be said about human memory, after a century of intensive research, is that unless detail is placed into a structural pattern, it is rapidly forgotten...

Third, an understanding of fundamental principles and ideas, appears to be the main road to adequate "transfer of training."...

The fourth claim for emphasis on structure and principles in teaching is that by constantly reexamining material taught in elementary and secondary schools for its fundamental character, one is able to narrow the gap between "advanced" knowledge and "elementary" knowledge.7

But there should be something more to discovery than the attainment of the concepts and conceptual schemes which fill out the structure of the discipline. Neil identifies this additional component as "dynamics."

Knowledge of structure, conceived as a set of interrelated principles in current good standing in a discipline, is abstract and static knowledge. While such knowledge, even though static, is preferable to isolated bits of information lacking any system of organization, it stops considerably short of being the essence of a field of knowledge. The dynamics of a field, which would constitute the means of continuing inquiry, is to be found in the key questions of concern to scholars in that field, in the methods or rules according to which data are sought and handled, and in the language and other symbolic tools employed.8

This thought is also present in several recent definitions of the term "discipline." Phenix writes:

A discipline is knowledge organized for instruction. There are three fundamental features, all of which contribute to the availability of knowledge for instruction and thus provide measure of the degree and quality of discipline. These are (1) analytic simplification; (2) synthetic coordination; and (3) dynamism.9

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Foshay identifies three characteristics of a discipline. "First, a discipline has a domain." Each discipline deals with information, the data, the relationships, and the phenomena appropriate to that discipline. Second, there is in each discipline, "... the way a scholar treats the data his discipline calls on him to deal with -- the data in the domain of his discipline." Finally, "... the history of a discipline is a part of its substance -- that is, that the way certain phenomena have been treated by scholars in the past is a part of the present knowledge of a scholar in the same discipline, and exercises a certain control over what he does -- ..."10

Schwab offers as guidelines, "for the construction of a quality curriculum,"

(a) that the aim of teaching and learning be an education that encompasses the best fruits of the disciplines; (b) that these fruits be taught and learned not as a rhetoric of conclusions but according to the extent and the sense in which they are true; and (c) that the extent and sense of truth be determined by an awareness of the structure of inquiry that produced them.11

Broudy attributes to Tykociner the classification of "bodies of knowledge" into five sets, which he implies are groups of disciplines:

1. Bodies of knowledge that serve as symbolic tools of thinking, communication and learning. . . .
2. Bodies of knowledge that systematize basic facts and their relations. . . .


3. Bodies of knowledge that organize information along routes of cultural development.

4. Bodies of knowledge that project future problems and attempt to regulate the activities of the social order.

5. Finally, there are the integrative and inspirational disciplines which create syntheses or value schema in the form of philosophies, theologies, and works of art.

While it may be questioned whether any one of the bodies of knowledge normally regarded as a discipline could be fitted neatly into one of these sets, significant characteristics of the various bodies of knowledge professed from the chairs of our universities are hereby defined. It might be possible to get at the structure of a particular discipline by identifying the body of knowledge involved in that discipline which fits into each of these categories.

We might say that a discipline has structure to the extent that the conventional knowledge in that discipline serves these functions. A "strong discipline," a discipline which is "well structured," would be one in which all of the five functions are clearly served.

Such a view of disciplinary structure, centered as it is on such functional verbs as serve, systematize, organize, project, and create, reflects the dynamism required by Phenix and recognizes the significance of structures.

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13 For example the discipline of chemistry: (1) conventions of symbolism and nomenclature -- symbolic tools; (2) laws, theories and conceptual schemes -- systematize basic facts and their relations; (3) history of chemistry and chemical technology -- organizes information along routes of cultural development; (4) industrial chemistry and chemical engineering -- project future problems and attempt to regulate activities; (5) here we may have to stretch a little, but to some of us, the literature of chemistry is a work of art and the contribution of chemical empirics to modern philosophy is generally recognized.
of the history of the discipline as a part of the discipline which Foshey insists upon.

If discovery learning is to lead to significant understanding of the structure of the discipline, concept attainment should be supplemented with a concern for concept development. The student should be led to an understanding of and experience with the kind of thinking involved in the discipline -- understanding of, and skill in the use of, the system of inquiry.

Inquiry Training

One of the techniques of teaching for discovery which has been most carefully studied is "inquiry training" as defined by Suchman. In this study, the student is shown a filmed demonstration of a relatively simple phenomenon and asked to develop an explanation of what he has observed. The instructor provides some guidance and structure to the inquiry through "yes" or "no" answers to the student's questions.

Working with fifth-grade students of above average ability, it has been found that three significant factors interfere with this mode of inquiry: (1) the students' lack of autonomy and productivity, it was concluded that this was the result of dependence on authority for "right" ideas from which to shape concepts; (2) the requirement that the student go beyond the kind of concrete operation with which he was familiar and use abstract propositional thinking was difficult for even the most

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gifted children, and (3) there was little recognition of assumptions made or factors involved in the hypotheses raised, thus, suggested "experimentation" was essentially replication with closer observation rather than a means of gathering relevant data and testing ideas. 15

It is concluded that the use of this device, the guiding of the student in the development of systematic questioning which leads to an acceptable explanation, can produce three significant educational outcomes: (1) the autonomous discovery of principles and generalizations makes learning of these principles and the information related to them more productive; (2) it gives the student confidence in the power of his thinking; and (3) the realization of his own ability to understand and control events in his environment motivates him to extended effort. 16

From this discussion of inquiry training through "discovery learning" and the study of the structure of the disciplines, we conclude that these efforts to bring about concept development through the use of the conventional knowledge of science have been productive. Their effect may be noted in the design of activities for the course under discussion. We have clearly stated our conviction that subject matter competence is an absolute necessity. However, the magnitude and diversity of conventional knowledge, and the accelerated rate at which it is accumulating make any particular choice of specific subject matter open to serious question. The selection of specific information, concepts, and general propositions should be incidental to the achievement of objectives other

16 Ibid., p. 168-69.
than competence in that subject matter. One of these other objectives is the development of the skills of inquiry.

We hold that evaluation of these methods of instruction by comparison with non-discovery methods is invalid. Each is trying to accomplish a significantly different, but equally necessary, part of the ultimate pedagogical task of educating for intelligent behavior.

The Case Study Method

One other approach to the indirect teaching of skills of inquiry should be considered in this discussion. The use of the history of science as the vehicle for developing understanding of science has been proposed many times. The Journal of Chemical Education presented such discussion thirty years ago. The value of the history of science in the general education program at the college level has also been noted.

The Case Study Method has developed directly from the work of Conant, Kuhn, and others in the course Natural Science 4: Research Patterns in Physical Science, at Harvard College.

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This course developed from a one-semester course for junior and senior college students using the "Case Study Method in Teaching Principles of the Tactics and Strategy of Science." In 1948 a full year course for freshmen and sophomores was developed. It was assumed:

... that a rather intensive exposure to the way in which certain scientific ideas have been developed will lead to an understanding of the processes by which physics, chemistry, and astronomy have advanced in the last three hundred years and are today advancing. ... Because of our emphasis in most instances on the details of the historical development of a new concept or conceptual scheme, and because of our use of the documents which first described the experiments in question or the new theory, we designate our procedure as the case history method.

The description of the course indicates its basic nature:

This course is intended to acquaint students who will not concentrate in physical science with the manipulative and intellectual procedures of the working scientist. These are displayed through detailed historical and technical study of selected investigations of the physical world. Each of these case studies is directed primarily to the discovery of those factors which determine the productivity of the investigation; the creative interactions of scientific, social, and philosophical activities provide a secondary theme. No comprehensive survey of technical products of scientific activities is attempted, but the students are expected to master technical and mathematical materials to the extent that these are necessary for an understanding of the case histories. The prerequisite is a course in physics, or in chemistry, or in general science with emphasis on physics or chemistry, taken in secondary school.

Nash says of the course:

In planning our presentation there are two points we hold ever before us: (1) we must not teach scientific facts and theories for their own sake, but as a means toward the end of understanding science; and (2) we must not hope to teach the persistent characteristics of the scientific enterprise in a pat, capsulated form --

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20 James B. Conant, on cit., subtitle.

21 Ibid., pp. 5-6.

22 Workshop in General Education, Harvard University, 1950, on cit., p. vii.
that is, "the scientific method." Thus we face the task of presenting various illustrative examples, with all their attendant raw material of facts and fancies; and, through an intensive examination of these illustrations, we try to guide our students to some recognition of the recurrent basic patterns of scientific endeavor and of real-life complexity that attends any of their specific manifestations.\(^{23}\)

Nash concludes that through the study of these "cases" of scientific inquiry we can overcome "The cult of fact" and "The cult of method."

\[\ldots\] these and cognate misconceptions may be encouraged rather than dissipated by the traditional specialists' courses in science \[\ldots\]. The evidence now available gives us some reason to feel that this approach [the Case Study Method] does indeed lead to a significant kind and amount of appreciation and comprehension of the scientific enterprise as it was and as it is -- or, in short, that it does indeed provide an understanding of Science.\(^{24}\)

Klopfer and Cooley\(^{25}\) extended this approach to the secondary schools through the development and study of the use of the History of Science Cases for High School and the program which is called the History of Science Cases Instruction Method.\(^{26}\) Through the use of a specialized instrument developed for the study,\(^{27}\) the effectiveness of this program

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\(^{23}\)Ibid., pp. 97-98.

\(^{24}\)Ibid., pp. 117-18.


in existing secondary school courses in biology, chemistry, and physics was studied.

It was concluded that:

... the History of Science Cases Instruction Method is definitely effective in increasing student understanding of science and scientists when used in biology, chemistry, and physics classes in high school. ... Moreover, when the students study under the HOSC Instruction Method, they achieve this significant understanding of science and scientists with little or no concomitant loss of achievement in the usual content of high school science courses.28

The specialized instrument designed to measure the "Understanding of Science" as defined in this work is one step toward independence from measures of achievement of competence in conventional subject matter of the disciplines as indication of the development of understanding of the discipline. The understanding which is supposed to be developed is measured through the students' critical interpretation of short passages relating to each of eighteen elements. These elements of the analysis of the understanding of science and scientists are classified into three areas:

Area I

Understanding about the scientific enterprise
1. Human element in science
2. Communication among scientists
3. Scientific societies
4. Instruments
5. Money
6. International character of science
7. Interaction of science and society

Area II

Understanding about scientists
1. Generalities about scientists as people
2. Institutional pressures on scientists
3. Abilities needed by scientists

Area III

Understanding about the methods and aims of science
1. Generalities about scientific method
2. Tactics and strategy of sciencing
3. Theories and models
4. Aims of science
5. Accumulation and falsification
6. Controversies in science
7. Science and technology
8. Unity and interdependence of the sciences

Special care was taken to assure that the specific cognitive tasks involved in the test items would not be taught directly.

We may conclude from this work that materials from the history of science can be productive of both subject matter competence as measured by a typical achievement test in science and understanding of science as measured by this special instrument. However, except as such achievement and understanding may be an indirect indication of successful participation in the processes of inquiry, we have no evidence as to the extent to which the pedagogical function of the development of skills of inquiry has been achieved in these activities.


Implications

From this brief review of the extensive work which has been done in "discovery learning," "inquiry training," and the development of understanding of the structure of the disciplines of science, we would draw four conclusions:

1. A discipline is a body of knowledge made up of (a) elementary data and information; (b) general propositions which relate these data; and (c) a system of inquiry.

2. Knowledge of the structure of a discipline involves: (a) acquaintance with the elementary information; (b) understanding of the general propositions; and (c) understanding of, and skill in the use of, the system of inquiry.

3. There is some evidence to indicate that an indirect approach to the teaching of the skills of inquiry through "discovery learning," "inquiry training," or "case study methods" may be effective for the development of skills of inquiry in the sciences.

4. The principal difficulty in verifying this assumed value of these methods stems from the fact that immediate goals are defined in terms of conventional subject matter competence and the instruments used measure this subject matter competence.

In terms of the system of thought described in Chapter III we would say that, at the college level at least, it is reasonable to approach the teaching of the system of inquiry directly. The knowledge about the system of inquiry, derived from the study of the history and philosophy of the discipline, is a significant part of the knowledge of
the discipline. Subject matter competence with respect to this subject matter (knowledge about the system of inquiry) is necessary for vocational competence within the discipline and for understanding of the discipline. It is therefore appropriate to assign activities designed for the development of such subject matter competence to the general education program.
CHAPTER V
THE FRAMEWORK FOR DESIGN

Introduction

We have set forth in this work a series of statement which, when brought together, should provide a basis for the design of activities for science in general education at the college level.

General education is defined as those planned experiences to which every person fully matriculated in an institution will be exposed.

The purpose of general education is threefold: (1) the development of the skills of inquiry by which knowledge in the various disciplines is derived, verified, and elaborated; (2) refinement and continued development of the skills of expression necessary for effective communication of this knowledge; and (3) the achievement of adequate subject matter competence so that the preceding two purposes may be implemented.

The function of science (the natural sciences) in general education is: (1) to present a well defined system of inquiry as an example of, and model for, structured inquiry in the various areas of conventional knowledge; (2) to provide examples of, and experience with, the forms of expression and style of writing used in science reporting; and (3) to provide opportunity for achievement of at least a minimal level of subject matter competence in the conventional knowledge of science.

In the education of a person in our democratic society, the school
serves to integrate, supplement, and elaborate the education received from other sources. Those educational experiences which are designed for the general education function of the pedagogical enterprise should be provided to (and required of) all students, unless it can be shown that they are provided more effectively or more efficiently through vocational or special education.

The programs of general education at the college level should be centered upon the methods of inquiry, using such subject matter as will illustrate the processes of inquiry. At the college level, a general education program may be designed for direct teaching of the system of inquiry.

The Design Criteria

From these conclusions, the following criteria are set forth as the basis for evaluating the proposal for a course in science as a system of inquiry to serve as the central activity in a program of general education in science at the college level:

Criterion 1 -- Subject Matter Content: Does the informational content of the course present a realistic description of the methods used in the natural sciences for the derivation, verification, and elaboration of the conventional knowledge of the disciplines?

In order to show that this criterion is fulfilled, it would be required that evidence be presented to support each of these contentions; (a) the process of inquiry has been analyzed into defined elements in such a way that the essentials of inquiry in all the disciplines of the natural sciences are treated; (b) the treatment of the elements defined
in the analysis is in keeping with the accepted literature in the history and philosophy of science; and (c) there is a synthesis of the defined elements into a unified whole such that the interrelatedness of the various disciplines is illustrated.

**Criterion 2 -- Method of Presentation:** Is the method of presentation appropriate to the essentials of scientific inquiry and to the students enrolled in the course?

In order to show that this criterion is fulfilled it would be necessary to show that: (a) the material is presented in a manner which is consistent with assumptions of the student capacity and potential for education as indicated by the admissions policies of the institution; (b) activities are provided in which the student participates in the kinds of experiences involved in scientific inquiry, at a level in keeping with his competence in the subject matter of science; and (c) there is a conscious attempt to present scientific inquiry as a dynamic process involving a growing body of conventional knowledge in the identification and solution of meaningful problems.

**Criterion 3 -- Integrity and Continuity of the Program:** Is the design of the course consistent with the overall structure of the program of science in general education such that the interrelatedness with other courses is evident?

Effectiveness of design according to this criterion would require that: (a) the general objectives of the course are continuous with the objectives of any prerequisite courses and subsequent courses in the program; (b) the subject matter and activities of the course are not unproductively repetitious of probable previous experience of the
students; (c) the subject matter and activities of the course are demonstrably preparatory to the next subsequent course in the program; and (d) the rationale basic to the design of the course is consistent with, or an integral element of, the rationale of the program.

**Criterion 4 -- Evaluation of Student Achievement:** Does the design of the course specifically indicate the immediate objectives of the activities of the course so that there is a functional definition of the outcomes to be used in the evaluation of student achievement?

Requirements for this criterion would be: (a) that there be a functional definition of the immediate objectives of the activities of the course; and (b) that it be shown that the instruments and techniques to be used in evaluating student performance do indeed provide a measure of the extent to which these objectives are fulfilled.

**Criterion 5 -- Evaluation and Development of the Course:** Does the proposal for the course include a proposal for a program of continuous evaluation of the course and for the modification and development of the course in terms of the results of this evaluation?

To meet this criterion it must be shown that: (a) there is provision for the accumulation of data on which to base the evaluation of the effectiveness of the course; (b) there is a realistic plan for the interpretation of these data; and (c) procedures are available or proposed through which effective modification of the course may be implemented.
Materials and Method

The course 40-161, Introduction to the Natural Sciences at Inter American University of Puerto Rico is scheduled as a four credit course, in three (sixty minute) periods of lecture and one (one hundred twenty minute) period of laboratory activities and discussion each week for fifteen weeks of one trimester. The lecture periods are attended by all students enrolled in the course, from sixty to one hundred students. The laboratory-discussion groups meet in smaller sections of twelve to twenty-four students.

The students are expected to attend all lectures and the laboratory-discussion section to which they are assigned each week. Each student is expected to study the text for the course, read such supplemental materials as are suggested and required, and participate in the activities of the laboratory-discussion section. Evaluation of student performance is made on the basis of a series of written examinations, the performance on a series of reading assignments, and the evaluation of the students record of laboratory activities.

The principal text for the course is the volume Science as a System of Inquiry. Appendix A presents portions of this text which illustrates its structure and organization. The headings in the table of contents indicate the elements of inquiry treated in the text. The summary sections from the various chapters indicate the general nature of the presentation. Chapter I: The Nature of Science, defines the

concept of scientific inquiry used in the course. Chapter IV: The Development and Communication of Concepts, is included as an example of the type of presentation used.

Supplemental materials and facilities - There is available to the students, a reasonable collection of library materials from the history and philosophy of science and science related literature in the central library of the University and in the collections of the Institute of the Natural Sciences. Appendix B presents a partial bibliography of these volumes. In addition, a supplementary volume was prepared by the instructor. This volume contains materials which the instructor felt would be of value and which were not available in concise form in the materials available to the student from other sources. It also contains directions to the student for the reading assignments and one set of laboratory activities which have been used in the course. Appendix C presents the table of contents and Articles VII, IX, and X of this volume.

In addition to these specific literature resources, the students are prompted to use current sources from popular journals and periodicals, and materials from other sources, such as their work in other courses at the University, in building an understanding of the broad applicability of the system of inquiry being studied.

The equipment and supplies available for the laboratory activities are adequate. About one half the work done in the laboratory is done

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on an individual basis. In those cases where the work is done in groups, discussion within the group and comparisons to bring out differences within the group are a part of the planned activities. Of course, there are cases in which group activities are required because of the limitations of equipment. In one trimester an exercise with the telescope was used. Only one telescope was available.

There have also been cases in which available equipment was not used because of time limitations or other restricting factors. Many possible opportunities for the use of facilities available in the community outside the University were neglected. ³

Lecture Activities - The three lecture periods each week are devoted essentially to lecture by the instructor. Generally the material covered in lecture corresponds closely in scope and sequence with that presented in the text. There is a great deal of use made of examples from the conventional knowledge and experience of the instructor in the natural sciences, particularly from the fields of chemistry, physics, and mathematics.

There is conscious effort on the part of the instructor to invite discussion within the class during the lecture period. This is occasionally successful, particularly on points raised from the

³There is, within driving distance of the University, the world's largest radio telescope. In spite of the obvious value of this installation as an illustration of advanced technology of observation and the extent to which the conventional knowledge of science extends and controls observation, this facility was never used. The instructor's excuse is budgetary limitation and lack of time necessary for making the arrangements.
philosophy of science. When this does occur it is difficult, because of the size of the class, for the lecturer to keep the discussion orderly without dominating the discussion. To set off the process, a highly controversial topic and a group of intellectually active and interested students are required.

Laboratory activities - The laboratory activities of the course are designed to give the students experience with the kinds of activities involved in scientific inquiry. Since the desired center of attention is the activity rather than the conventional knowledge involved, the activities are carried out through the use of relatively simple systems of equipment and concepts.

Exercises are designed to give the student experience with the elements into which inquiry is analyzed, observation and record keeping, the development of concepts, the development and communication of conceptual systems, the development of logical models, the use of classification systems, and criticism. Article X of the Supplements, which gives the student laboratory assignments used in the first trimester of the 1964-65 academic year, is presented in Appendix C.

There has been considerable variation in the laboratory activities used in successive trimesters in which the course has been offered. However, the spirit of the activities has been retained throughout. In order to delineate this spirit more effectively, an extended discussion of one of the activities used is presented in Appendix D.4

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Reading assignments - In each trimester the students have been assigned, as part of the course activities, the preparation and submission of six reading assignments. Article IX of the Supplements defining these assignments is presented in Appendix C.

The principal function of the reading assignments is to bring the student into contact with the literature available and related to the material presented in the course. It is hoped that by allowing the student wide latitude in his selection of material, the broad applicability of the system of inquiry would be emphasized. An attempt was made to design the assignments so that attention would be centered on the process of inquiry rather than on the conventional knowledge reflected in the material read.
CHAPTER VI

THE PROGRAM OF EVALUATION

Introduction

There are three aspects of evaluation involved in this work, the evaluation of student performance for purposes of grading achievement, the evaluation of the course for purposes of development, and the evaluation of the program in terms of the criteria set forth in Chapter V. The three elements of evaluation are interrelated yet, in a sense, distinct.

The evaluation of student achievement is an integral part of the educational activities of the course. Whether we like it or not, we must recognize that most college students are more directly moved by the pressure for grades than by pure intellectual drive. The nature of the devices and techniques used for grading purposes do, to a very large extent, determine what most students strive to learn.

The evaluation of student performance is also a significant factor in the evaluation of the course. The extent to which students in the course achieve the objectives represented in the grading instruments is one, readily accessible, source of data on which to base the evaluation of the course for purposes of development. Obviously, it is not the only source of data. Other data must be obtained if the course is to be more than an excuse for giving a grade.

The third element of evaluation; the evaluation of the design
of the course, involves both the grading of student achievement and the continuing development of the course. It will, therefore, be dealt with in this chapter.

Evaluation of Student Achievement

As indicated in our analysis of the objectives of pedagogy (Chapter III, page 30), it is at the level of operational evaluation that objectives are defined in terms of specific, observable student behavior. It is objectives at this level which must be used as the basis for evaluation of student achievement.

In the development of the Taxonomy of Educational Objectives, the Committee of College and University Examiners has set forth a systematic approach for the derivation and definition of objectives at this level. Our principal objective at the level of pedagogical function has been stipulated as the development of skills of inquiry. If we can derive a meaningful analysis of this general objective in terms of the operationally defined objectives of the Taxonomy, it should provide a basis for the evaluation of student achievement for grading purposes.

In the Taxonomy, the committee defined three major classes, or domains, in this set of objectives:

The cognitive domain, ... includes those objectives which deal with recall or recognition of knowledge and the development of intellectual abilities and skills. ...

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The second part of the taxonomy is the affective domain. It includes objectives which describe changes in interest, attitude, and values, and the development of appreciations and adequate adjustment.

A third domain is the manipulative or motor-skill area, the psychomotor domain. Although we recognize the existence of this domain, we find so little done about it in secondary schools and colleges that we do not believe the development of a classification of these objectives would be very useful at present.2

As indicated in this description, the psychomotor domain has not been delineated. It is possible that there may be some valid objectives which could be defined within this domain that would be appropriate to the course under discussion (i.e., the development of eye-hand coordination necessary for the adjustment of focus of an optical instrument). However, such objectives would seem to be rather highly specialized for inclusion as objectives in a general education course. We are, as were the members of the committee, content to leave such objectives undefined and trust to their incidental achievement and evaluation.

The committee presents a more complete definition of the affective domain:

... objectives which emphasize a feeling tone, an emotion, or a degree of acceptance or rejection. Affective objectives vary from simple attention to selected phenomena to complex but internally consistent qualities of character and conscience. We found a large number of such objectives in the literature expressed as interests, attitudes, appreciations, values, and emotional sets or biases.3

This description of the objectives in the affective domain indicates the problems which might be anticipated in any attempt to use such

objectives as a basis for the design of instruments to evaluate student achievement. This would also account for the fact noted by the committee.

When we looked for evaluation material in the affective domain we found it usually in relation to some national educational research project or a sponsored local research project (for which a report had to be written). Only rarely did we find an affective evaluation technique used because a group of local teachers wanted to know whether students were developing in a particular way.4

Objectives in the affective domain involve the value system of the student. While commitment to an acceptable system has been set forth as one of the objectives of pedagogy, this does not imply that there is one such system. We share with Dressel5 concern over the possibility that the pressure for grades might result in the students' pretending the required characteristics if affective objectives are used for the design of instruments for evaluation of student achievement for grading purposes. To the extent that this might occur, achievement of those objectives would be negatively affected; the examination would be a mis-educative experience.

For this reason, we restrict the objectives used for the design of instruments for evaluation of student achievement for the purpose of grading, to the cognitive domain. We might hope, as Mason has assumed,6

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that the achievement of affective objectives related to science, at the college level at least, is measurable through evaluation of achievement of cognitive objectives. To the extent that this may be true our instruments may measure attitudes, interests and appreciations. They are designed to measure recall, recognition, and understanding of the subject matter of the course.

In the design of this course there are three bodies of material used to evaluate student achievement; written examinations, reading reports submitted by the students, and the duplicates of the laboratory record maintained by the student.

In the evaluation of the laboratory reports, it was necessary that particular care be taken to avoid evaluation in terms of the instructors interpretation of affective objectives. Only when the report was to be used by other students, as in the exercise on the development of logical models (exercises seven and eight, Appendix C) was the form of the report specified.

One of the significant objectives of the laboratory activities is to help the student to develop habits of careful record keeping. This depends on the development of constructive attitudes toward record-keeping and interest in maintaining useful records. It was, therefore, established that in the grading of the laboratory reports, criteria involving form or structure of the organization of the report or expression of ideas would not be used. In this way, it was hoped, the freedom of the student to develop his habits of careful record keeping, rather than copying those of the instructor, could be retained.

The only criteria which are used in evaluating the laboratory
reports are criteria involving the completeness of the report. If the student's record is such as to indicate that he was present during the activity and attentive to the experiences which the instructor feels are essential to the activity, the student is given full credit for that report. If the report of some experience is missing from the report or not recognizable as such to the grader, the credit for that report is reduced.

Criticism of the report is included with the report of evaluation, so that the student might be helped to see in what manner the reports of succeeding activities could be improved. The factors considered in the evaluation were identified so that the student would not gain the impression that his grade had been affected by his exercise of initiative. Even so, in the sequence of four trimesters, there developed a significant uniformity in reports from the median group of students.

The evaluation of the reading assignments is based essentially on the extent to which the questions asked in the assignment are dealt with. If a reasonable answer is given for each of the questions posed in the assignment, full credit is given for the report. If the form indicated by the assignment is followed, it is more probable that the answer, if it exists, would be recognized. It is not so surprising that a relatively standard form developed for the reading assignments.

Reading assignments four, five, and six (see Appendix C) are particularly difficult to evaluate. Since these are sequential assignments, students who submit marginal or submarginal papers in reading assignments four or five are asked to confer with the instructor before
proceeding. Because of the number of students involved and the press of time the evaluation and criticism of acceptable papers is superficial.

The examinations used contain a number of multiple-choice items (generally thirty for each one hour examination and sixty for the two hour final examination), and three questions which require some organization and exposition of ideas (essay questions). A sample test is presented in Appendix E. The multiple choice items are selected from a stock of questions so as to give a balanced sample with regard to the identified cognitive objectives of the course. A listing and definition of these objectives is presented in Appendix F.

In arriving at the final grade in the course for the individual student, the scores made on each of the four elements of evaluation; laboratory reports, reading assignments, two one hour examinations, and the two hour final examination, are adjusted so that the highest score on each represents one fourth of the highest total. The adjusted totals are then "scaled" by the instructor. The grade represented by the student's total score in this scale is the reported grade for that student.

Developmental Evaluation

The second aspect of evaluation involved in the design of the course is the continuing evaluation for purposes of development. If we are to teach scientific inquiry as a dynamic process, we must be true to our teaching. We must devise a program for the evaluation of the course and its development in keeping with the dynamic spirit of inquiry.

The most readily available data from which to judge the
effectiveness of the course are the results of the evaluation of student achievement used for grading purposes. Analysis of the student response on the various instruments and items used to evaluate student achievement can be used as an indication of the effectiveness of the activities of the course in fulfilling the objectives which those instruments are supposed to measure. If a large percentage of the students fail to perform adequately on a particular instrument or item, it can be concluded that either the instrument is invalid or the activities of the course are inadequate for the fulfillment of the objective involved.

Since the pedagogical objectives for the course under discussion are significantly different than the objectives on which available standardized tests are based, comparison against these standards, as a measure of validity, would be unproductive. Therefore, the decision as to whether general failure on a particular item of any of the evaluation instruments is due to a weakness in that item as a tool for evaluation or to a deficiency in the design of the course activities is, in the end, a subjective judgement which must be made by the instructor or an observer.

If the subjective nature of this decision is acknowledged, it can be used as the basis of an opinion as to the effectiveness of the course in achieving the objectives represented in the design of the evaluation instruments. Correction of such weakness in the course as may be identified should be made through modification of the activities of the course by the instructor. As presently designed, the activities of either lecture, laboratory, or reading assignment are sufficiently flexible to allow such modification.
Another source of opinion as to the effectiveness of the course is the instructor's subjective judgment of evidence of student achievement of affective objectives of the course. While we have, for reasons previously cited, not used affective objectives directly in the design of instruments for grading of student achievement, the instructor can and should consider evidence of student interest, attitude, and appreciation which can be drawn from observation of student response to the activities of the course. The instructor will, because of the nature of the teaching process, use such evidence as the basis of his day by day planning of activities.

It would be of great value for the developmental study of the course if the instructor could maintain a diary of his impression of student response throughout the term in which the course is taught. Even though the writer has been unable to maintain such an instructor's diary in usable form (several attempts have been made), we are still convinced that such a diary would have value in the developmental study of the course.

A second, considerably less subjective, means of obtaining evidence of the development of student interest, attitude, and appreciation would be the maintenance of a diary of student response to the activities of the course by an impartial observer of these activities. If it were possible to obtain assistants for this task, one term could be spent in establishing procedures for observation and record keeping and establishing protocols for interpreting the evidence obtained. Once the procedures and protocols were established, a continuing program of evaluation and development would be possible. The preliminary study should
also be helpful in developing procedures for the maintenance of the instructor's diary as well.

A third method for the evaluation of the course would be the development of a specialized instrument for the measurement of the achievement of affective objectives in a manner similar to that used by Klopfer and Cooley in their study of the case study method. Through such a program for the development, administration, and interpretation of an instrument to measure the extent of achievement of the affective objectives of the course, a meaningful program of development could be carried out.

Either or both of these last two means of developmental evaluation would assure sound development of the course and the program of which it is a part. Unfortunately, both are beyond the financial resources of the writer in his present position.

**Evaluation of the Course Design**

The third element of evaluation to be discussed is the evaluation of the design of the course in terms of the criteria set forth in Chapter V. Here the evidence on which to base the evaluation must be drawn from the proposal for the course and the program of which it is a part. Let us summarize briefly the proposed program.

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It is proposed that the program for general education in science should be composed of three courses of one term each. The first course would be the general education course in science as a system of inquiry discussed in this work. This would be followed by, and prerequisite to, two courses designed and taught within the academic departments representing the accepted disciplines within the natural sciences. One of these courses would be elected from alternatives within the field of the biological sciences (botany, zoology, and related disciplines). The other would be elected from alternatives within the field of the physical sciences (physics, chemistry, earth science, etc.).

Each of the alternatives from which the two courses are to be elected would be designed to present a study in depth of a relatively narrow segment of the conventional knowledge of the discipline involved. Within this limitation, the design of the course would be left to the department involved.

All students would be required to complete the course in science as a system of inquiry except those for whom it can be shown that the student would have equivalent experience in his vocational program or the special education program. Vocational courses or segments of the special education program might be used to satisfy the subsequent requirements if the required depth of study is evident. Any general education program in mathematics would be in addition to this proposed program in the natural sciences.

We have set forth five criteria (Chapter V, pages 55-57) on which to base the evaluation of the design of the course within this program.
Let us consider these individually:

**Criterion 1 - Subject Matter Content:** Does the informational content of the course present a realistic description of the method used in the natural sciences for the derivation, verification, and elaboration of the conventional knowledge of the disciplines?

In the general text for the course, which provides the basis for the lecture activities, inquiry is analyzed into these elements: (1) observation and record keeping, (2) the development of relationships, (3) the building of concepts and conceptual schemes, (4) problem solving, and (5) research. Each of the elements is functionally defined and delineated. The essential factors involved in each of these activities of inquiry are discussed and experienced in the laboratory activities.

In using the text in four successive trimesters, the writer has found four areas to be inadequately treated. These are: (1) the structuring of systems of thought and deductive explanation and prediction within such systems, (2) the development and use of conventional systems of symbolism and nomenclature, (3) the identification, derivation, and clarification of meaningful questions and problems for inquiry and research; and (4) the nature and significance of intellectual honesty.

The first two of these have been effectively presented in the lectures for the course. The third and fourth have been attempted, but the writer is far from satisfied with the effectiveness of the presentation. It is hoped that in succeeding editions of the text, these areas will be more adequately treated.

The treatment of the elements into which inquiry has been analyzed may be open to criticism. The literature in the philosophy of science
based on the logical approach to the development of scientific thought\(^9\) may be considered to be neglected in the text. Several of these sources are cited in the bibliography of supplemental readings (Appendix B) but the students in the course have made little use of the works of this type which were available to them. The lack of logical rigor in the presentation in the text and the lectures leads the students away from such sources. It is only the student with sufficient initiative to develop his own criticism who has gone to these sources for support.

The presentation in the text and the lectures follows more closely the line of thought represented by the historical approach to the philosophy of science. The views of scientific inquiry presented in the writing of Duhem\(^10\) and the current work of Kuhn,\(^11\) Toulmin,\(^12\) and Hesse\(^13\) have more markedly affected the treatment of the elements into which


inquiry has been analyzed.

A view of the function of the various simple elements in a dynamic developmental process is presented in Chapters VI: Scientific Methodology and Chapter VII: The Structure of Research. Chapter VIII: The Classification of Scientific Knowledge illustrates the interrelatedness of process and content among the various disciplines.

The unity of conventional knowledge and the interrelatedness of its various segments is further illustrated by the broad choice of examples used in the activities of the course. The nature of the course, as an introduction to the natural sciences, and the interest and experience of the instructor have resulted in relatively great use of examples from the physical sciences in the planned activities of the course. However, the reading assignments and discussion allow a broader view of the function of inquiry in the other areas of human knowledge. The flexibility of the course in the use of illustrative material from conventional subject matter provides a potential in this direction which is limited only by the interest and ability of the students and the instructor to extend the discussion beyond the examples used in the presentation.

Criterion 2 - Method of Presentation: Is the method of presentation appropriate to the essentials of scientific inquiry and to the students enrolled in the course?

The materials and presentation of the course require no specific student background beyond a reasonable facility in reading, writing and arithmetic, adequate vocabulary to serve as a basis for study, and the intellectual interest and integrity which serious study requires. It is
assumed that any student who has made a satisfactory score on the admissions tests used (The College Entrance Examination Board, Scholastic Aptitude Test or the Admissions Examination of Inter American University) meets these conditions. Of the students enrolled in the course at Inter American University, there was a group for whom study in the English language is a problem. For these students, the methods of the course were inappropriate.

The flexibility allowed the instructor in the selection of illustrative materials provides the means through which the course may be adjusted to the general level of academic background represented in the class. This openness to any and all information for consideration also leads to the introduction and discussion by the students in the class of ideas and concepts derived from sources other than the school. The interrelatedness within the body of conventional knowledge which is developed in the course, makes it possible for each student to apply the principles of inquiry to his own learning regardless of his background of interest and achievement.

The textual materials and the sequence in lecture are designed so that each of the essential concepts is introduced in relatively simplified context. The concept is then extended in meaning through successive application. In this way the student experiences the growth of conceptual meaning through a broadening of the context. The laboratory activities of the course are designed to give experience in such activities as observation and record keeping, development of concepts and conventional terminology, and the derivation of statements of relationships. In order that the attention of the student may be centered
upon the process of inquiry rather than the conventional knowledge involved, simple equipment and conceptual systems are used. Again, the flexibility in design allows for adjustment in terms of the normative level of interest and background of the class and for individual differences in the class.

Throughout the course, in all its activities, the processes by which conventional knowledge is derived, verified, and elaborated form the central theme. Scientific knowledge is characterized as continually subject to modification and extension through refinement of observation and criticism.

Criterion 3 - Integrity and Continuity of the Program: Is the design of the course consistent with the overall structure of the program of science in general education such that the interrelatedness with other courses is evident?

According to the rationale presented in this work, the particular function of science in the program of general education at the college level is to present a well-defined system of inquiry as example and model, to give experience with the style and form of scientific literature, and provide for the development of intellectual confidence and self-assurance so that the student may be willing and able to achieve competence in the subject matter of importance to him.

The course under discussion is the first course in the program. It is designed to provide an understanding of science as a system of inquiry. It is to be followed, in the proposed program, by two courses in which particular concepts and conventional knowledge of science are studied in depth. In each of these subsequent courses a relatively
narrow segment of scientific knowledge will be presented so as to show the development of the concepts and conceptual schemes involved from their simple exploratory phase to their application in the current development of new knowledge.

The knowledge of the process of scientific inquiry presented in the initial course provides the base upon which to build an understanding of the substance and structure of any particular segment of the disciplines of science. This would serve as preparation for the formal study of any segment selected. If the objectives of the program are fulfilled, the student will be led to a continuing study of such scientific knowledge as his interest and needs may require. We would say that the objectives throughout such a program are continuous.

The presentation of science as a system of inquiry in the proposed course is not repetitious of previous experience of most students. The secondary school may have provided, for a limited number of students, somewhat similar experiences. (Some of the laboratory activities used in the course are similar to, in fact derived from, activities developed in the new secondary science curriculum programs.) However, the flexibility in use of illustrative material which is possible in this course allows for modification for any group of individuals for whom these activities would be unproductively repetitious.

Criterion 4 - Evaluation of Student Achievement: Appendix E presents the analysis of objectives of the course. Achievement of cognitive objectives is measured for the purpose of grading. Written examination is used to measure achievement of objectives of knowledge, comprehension, and application. Reading assignments and laboratory
reports are used to measure achievement of objectives of analysis, synthesis, and evaluation.

**Criterion 5 - Evaluation and Development of the Course:** The preceding section of this chapter deals with this phase of evaluation. The current use of subjective evaluation is described. Two proposals are made for more objective evaluation to be implemented when financial resources become available.
CHAPTER VII
SUMMARY AND CONCLUSIONS

Summary

The purpose of this work is to set forth the function of science in general education at the college level, to support this statement with appropriate authority and by rational argument, and to show that the course which is discussed does effectively provide the base for a program which will fill this function. The course discussed presents science as a system of inquiry. The materials and activities of the course were designed and used in four successive trimesters at Inter American University of Puerto Rico.

General education is defined as those experiences to which all students are exposed. Its essential purposes are: (1) the development of skills of inquiry; (2) refinement and continued development of skills of expression; and (3) the achievement of such subject matter competence as the preceding two purposes may require.

The function of science in general education is: (1) to present a well-defined system of inquiry as an example of, and model for, structured inquiry; (2) to provide experience with scientific expression; and (3) to provide a base for continuing study as interest and need demand.

From current work in teaching through inquiry it is concluded that, in college, it is reasonable to approach the teaching of a system
of inquiry directly. Knowledge about inquiry is a significant part of the knowledge of the discipline involved. Development of competence in this subject matter is part of the function of general education.

It is held that the study of inquiry, with study in depth of relatively narrow segments of the conventional knowledge of the sciences, should give the college student a willingness and ability for further study as additional need develops. On the basis of these assumptions and conclusions, five criteria for evaluating the design of the course are set forth.

**Conclusions**

Conclusions drawn, in terms of the five criteria, are:

**Criterion I - Subject Matter Content:** Does the informational content of the course present a realistic description of the methods used in the natural sciences for the derivation, verification, and elaboration of the conventional knowledge of the discipline?

The materials and activities of the course are based on an analysis of scientific inquiry into the elements of observation and record keeping, the development of relationships, the building of concepts and conceptual schemes, problem solving, and research. Each element is delineated and functionally defined. The treatment of these elements is in keeping with current writing from the historical approach to the philosophy of science. In the discussion of problem solving and research, the synthesis of these elements into a unitary dynamic process is achieved. In the discussion of the classification of conventional knowledge, the interrelatedness of all knowledge is stressed.
Weakness with respect to logical rigor and deficiency in the areas of the structuring of systems of thought, conventional nomenclature and symbolism, the identification and clarification of problems, and the nature and significance of intellectual honesty, is noted.

Criterion 2 - Method of Presentation: Is the method of presentation appropriate to the essentials of scientific inquiry and to the students enrolled in the course?

The design of the materials and activities of the course are in keeping with the assumptions as to general ability and educational background of college students. The design of the course is sufficiently flexible to accommodate any reasonable variation from the assumed background.

Throughout the course, the dynamic character of inquiry is the central theme of the materials and activities of the course. Conventional knowledge of the sciences is presented as the medium through which problems may be identified and solved.

Criterion 3 - Integrity and Continuity of the Program: Is the design of the course consistent with the overall structure of the program of science in general education such that interrelatedness with other courses is evident?

No specific preparatory subject matter competence is necessary for the course. Satisfactory completion of the activities of the course will prepare the student for serious study of any segment of the conventional knowledge of the natural sciences. The flexibility of design of the course allows for modification so as to avoid unproductive repetition of previous experience. In terms of the rationale presented, the
course provides for the integration of conventional knowledge involved in other educational experience in and out of school.

**Criterion 4 - Evaluation of Student Achievement:** Does the design of the course specifically indicate the immediate objectives of the activities of the course so that there is a functional definition of the outcomes to be used in evaluation of student achievement?

Analysis and definition of the immediate cognitive objectives of the course is presented. Written examination effectively evaluates the extent of achievement of objectives of knowledge, comprehension, and application. Reading assignments and laboratory reports are used to evaluate the achievement of objectives of analysis, synthesis, and evaluation.

**Criterion 5 - Evaluation and Development of the Course:** Does the design of the course include a proposal for a program of continuous evaluation of the course and for modification and development in terms of the results of this evaluation?

The current use of subjective evaluation is described. Two proposals for more objective evaluation of the effectiveness of the course in the proposed program are set forth. The course, as presently designed, is sufficiently flexible to allow adjustment of material and activities to compensate for any weakness evident from this evaluation.

**Recommendations**

In order that the identified weaknesses in the course may be corrected and the development continued, the following are recommended:

1. A new edition of the text should be prepared which will treat
adequately the four areas of weakness noted. Suggested supplemental reading and laboratory activities should be included with each chapter so that overall student activity may have better continuity.

2. It would be desirable that the course be used at another institution to test its wider applicability. If the course is found to be satisfactory in this new environment, a "Teachers' Guide" should be prepared to facilitate propagation of the course.

3. As soon as resources are available, the proposed evaluation should be carried out, so that continued development may lead to a more effective course of this design.

The new edition of the text is in preparation, and the course is being further developed at Central Florida Junior College, Ocala, Florida.
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APPENDIX A

EXCERPTS FROM THE TEXT:

SCIENCE AS A SYSTEM OF INQUIRY

Second Trial Edition
by

Charles K. Evans

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Head, Department of Science Education
Inter American University of Puerto Rico
Inter American University Printing Office
San German, Puerto Rico
June, 1964
This book has been written to serve as a guide to the activities of the course Natural Science 161, An Introduction to the Natural Sciences, at Inter American University of Puerto Rico. There is no attempt at a scholarly treatment of the history and philosophy of science. The book is designed to give continuity to a series of lectures, laboratory exercises, and collateral readings which the student will be exposed to in the course.

The analysis of scientific inquiry presented is that of the author. Many such analyses of science could be made, any one of which might be better for a particular purpose. This is the one which this author prefers for the purposes of this course.

The author is indebted to literally hundreds of people for their contributions to this volume -- teachers, students, co-workers, and writers whose works he has read. It is his hope that this volume may give to others some small measure of the intellectual stimulation and satisfaction he has derived from those to whom he owes so much.

C. K. E.
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CHAPTER I

THE NATURE OF SCIENCE

The Character of Natural Science

"This is the age of science." How many times have you heard this phrase? When you hear it, of what do you think? Of the wide choice of food and fiber which has been developed and improved as a result of scientific advancement? Of the rapid travel and communication which has made it impossible for us to isolate ourselves from the rest of the world? Of rockets to the moon and space stations above the earth? Of hundred-megaton bombs with which we can completely destroy civilization as we know it? What does science mean to you?

If we are going to write and talk about science, perhaps it would be a good idea to start by considering what it is we are talking about. We will see later how difficult it is in science to have the careful definition of terms we would like, but we can begin by setting out one definition of science which may serve as a starting point. Let us consider as science any body of knowledge organized so as to increase man's understanding and use of his environment to improve his way of life. As we proceed with our discussion of the nature of science, our definition will take on more meaning. We will find that this definition is in some ways not satisfactory, but it will do for a start.

When we look closely at our definition, we find that several assumptions must be made if it is to be meaningful. First we must assume that man's environment is understandable, that the universe in which man exists operates according to some unifying principles, that nature has natural laws. To us this may seem too obvious to mention but we must remember that men, probably just as intelligent as any of us, lived for thousands of years believing that the world around them was controlled by errant spirits, free to act on impulse and whim. In such a world, understanding would be difficult and control, if it could be had at all, could only be obtained by begging or bribing these spirits to be kind. In such a world, we might develop a science of the psychology of spirits but a natural science such as we are talking about would be impossible.

A second assumption is that man is capable of understanding. Even the things of the world controlled by errant spirits could be used by man. Of course, not every individual could understand the demands of the spirits, but the witch-doctor, the high priest, or the special votaries of the gods could be depended upon. Some one has always been
available whom we could trust to interpret the demands of nature, but we must assume that any individual with normal mental facility and appropriate education is capable of understanding the world. This is not an easy assumption. One of the things you will find as you work more deeply into the study of science is that at our very best our understanding of any of the things around us is incomplete. I do not understand fully the way in which these writings are converted into ideas in your mind (I sincerely hope that they are), but I must have faith in the capability of mankind, someday, somewhere, to develop such understanding. We must further assume that once such understanding has been developed by some individual that it will be communicated to others so that this understanding may bring about improvement in the process.

A third assumption which we must make is that the unifying principles of the universe remain the same throughout all space and time. If this were not so, it would be pointless to try to understand them. Perhaps you have met problems which arise from differences in laws and customs. You have certainly heard some of the common jokes about English drivers in America and American drivers in England. Consider what would happen if the principles upon which your automobile is designed changed from one place to another. What would happen to our space program if the basic laws of motion were different on Venus than on the Earth? How could we plan for the future if the properties of the elements were to change so that next week the things which we know today no longer exist? Of course, we must admit that most scientific statements of principles do change. Newton's laws of motion have been revised as a result of new developments and discoveries. Dalton's indestructible atom has been destroyed. But these are not the result of changes in the fundamental principles. Rather, they reflect changes in our understanding. We must assume that the ultimate principles are forever fixed, the changes occur because we are getting closer and closer to the understanding of these principles.

With the assumption of an orderly, understandable, and dependable nature, we may proceed with the derivation and organization of knowledge so that we may understand our environment and use it to improve the conditions in which we live. We can develop a natural science.

The Relation of Science and Technology

If our definition of natural science is accepted, it is seen that there are at least two significant aspects, understanding and use. Both must be had if we are to have science. Yet these two aspects of science are often treated as if they were distinct. The aspect of understanding is often isolated under the name "pure science" or "theory," while the aspect of use is called "applied science" or "practice." And the great debate over the relative importance of theory and practice has raged for centuries.
The pro-practice debater can argue with good spirit that the control and use of the natural environment is what makes man, man. As long as man has been on earth, scientific discovery and invention have led the way from the Neanderthal spear to the automated steel factory. The oldest and greatest discovery of science is fire and the most important invention of the scientific mind is the wheel.

Most of us think of science in terms of the material progress which has been produced. This is reflected in the opening paragraph of this book. To the non-scientist the significance of modern science, for good or evil, is reflected in that fact that almost everything you buy today contains materials or has been made by processes which were unknown thirty years ago. To many people this is science.

Yet the pro-theory debater can argue just as well that it is only after an understanding of the process has been developed that discoveries and inventions can be used efficiently. While man used fire for thousands of years, it was not until he stopped worshipping it and tried to understand it that he could use it efficiently. Not until a long series of explanations had been disproven and discarded did the modern theory of combustion make possible the confinement and widespread use of fire that we know today.

But the supporter of pure science does not feel that this is his most potent argument for theory. The theoretical scientist is like the mountain climber who climbs the mountain because it is there. To such a man the essence of humanity is understanding. There is no such thing as a foolish question if it is honestly asked. Every honest question deserves an answer. It is the job of science to give it an honest and rational one. We might say that the assumption that the sun will rise again tomorrow is a significant act of faith, but we don’t have science until we wonder why.

Science as Inquiry

For our immediate purpose, it is not necessary that we settle this debate. Our definition of science requires both understanding and use. But it requires something more. It requires the organization of knowledge. In this work we are primarily interested in this third aspect of science. Whatever the aim of science may be, it must, to be science, have organization. Over the thousands of years of growth in natural science, there has developed a pattern for the derivation and organization of knowledge. This pattern of thought is what we call the system of inquiry. In this work we will be interested not so much in what science is about as how the scientist might go about it.

It must be recognized, however, that what we are saying is not meant to be descriptive of the way in which science has developed over the years of human thought. The history of science is interesting of
itself and we would hope that you might become devoted to it, but the
system which we deal with here is a simplified version of our interpre-
tation of the things a scientist does which make his work scientific.
Neither are we going deeply into the beliefs of scientists about scien-
tific knowledge. This is the realm of the philosophy of science. We
have already expressed, and will continue to express, something of our
philosophy. Again we might hope that you will find the philosophy of
science of sufficient interest to study it further. Our philosophy is
reflected throughout this work, but we will not give it to you to keep.
You must develop one of your own.

For the purposes of this work, we will analyze the process of
systematic inquiry in science into five elements: observation, the
development of relationships, the building of concepts and conceptual
schemes, problem solving, and research. We will see that these are not
distinct segments of the process. Scientific inquiry is a conscious
ongoing activity of the human mind. It cannot be broken down into
distinct steps any more than the process of walking can be. But we can
improve our understanding of the walking process by analyzing it into
the elements of imbalance, nerve stimulation, muscle contraction, and
reestablishment of equilibrium. Such an analysis is an important part
of the system of inquiry which we call science. We will treat the
process of analysis in our discussion of problem solving. But such an
analysis does not imply that scientific inquiry is characterized by
distinct steps to be taken in specific order. Our analysis is one of
many which might be made. It is made in the hope that it will help us
to develop better understanding of science as a system of inquiry.
CHAPTER II

OBSERVATION IN SCIENCE

Summary

When we are consciously aware of the existence of something we may say that we have observed it. If we are to effectively observe our environment, we must sort out from the many stimuli assailing our senses, those of importance at the moment. Yet we must also be alert to other things which we have not thought to be important but which may affect the outcome of our observation. We must observe closely but with an open mind.

But observation can never be absolutely complete and accurate. We must do the best we can with what we have and leave it to other men or another time to improve on it. This requires careful record keeping. Careful record keeping requires careful use of language. Our most accurate language is the language of measurement. Within the limits of accuracy of the measuring instruments and the man using them we can feel sure of the accuracy of an observation which is reported quantitatively.

To a large extent, especially in the beginning of scientific inquiry, we observe the things which are going on around us in everyday life. As our systematic inquiry becomes more sophisticated, we must plan our observation. For planned observation in the natural environment we must consider the time, the place, and the conditions under which the observation is made. These must be made a part of the record of the observation so that it may be of use to others.

If we can, we try to control the environment in which we make our observation. This may take the form of the creation of an artificially controlled environment in a laboratory, or planning of controlled observation in the natural environment. In either case it is important that the conditions under which the observation is made be a part of the report so that others will know the extent to which the observation may be of use to them and so that the observation may be repeated under as nearly the same conditions as possible so as to minimize the uncertainty.
CHAPTER III
SEEING RELATIONSHIPS

Summary

If we wish to understand and use our environment, we must find relationship among the things we observe. Basically there are two directions we can move in developing relationships. We can go from the specific instance to a general conclusion; this we call the process of induction. Or we can go from generalization to a specific conclusion; this we call the process of deduction. Since our observations are the basis of both these processes, we can never be sure that our conclusions are correct. We must always be willing to test our conclusions by further observation.

When we are trying to see relationship among a series of observations of a part (or system) of our environment, it is often helpful if we can find some other system similar to it for which we have some understanding. To the extent that the systems are similar we say that they are analogs, each is the analog of the other. To the extent that the analogy is valid, relations between corresponding parts of the two systems will be the same. But we must always remember that analogy is never perfect, we must always check our conclusions by further observation.

It is often helpful, if no analogy can be found, for us to construct an analog. This may be a physical model or it may be thought out, an ideational model. We can then reason from the analogy between our model and the system we wish to understand.

The richest source of ideational models for scientific inquiry is the logical systems of mathematics. The scientist makes great use of mathematical models because the logic on which the mathematical systems are based is so nearly perfect. But again we must remember the dangers of reasoning from analogy. Conclusions, though mathematically derived, can never be better than the observations on which they are based.
CHAPTER IV
THE DEVELOPMENT AND COMMUNICATION OF CONCEPTS

Introduction

As we observe our environment and see relationships which exist between its elements, we develop ideas which help us to understand and use the things around us. In order to communicate these ideas to others and to use them ourselves, it is necessary that we express them in words and other symbols. This book is simply the expression of a series of ideas which the author holds, in words which he hopes you understand. The author has a cluster of ideas about science, about observation, about relationship, which he has tried to put into words. We say that the author has a concept of science, a concept of observation, a concept of relationship. The words are his expression of these concepts. When we read or hear the verbal expression of a concept held by another person, it strengthens or alters our concept. Our concept develops from our observation, it is strengthened and modified by our communication with others. For the purpose of this discussion, we might say that a concept is a cluster of ideas which may be expressed by a relatively simple verbal or symbolic expression. A concept is the private property of an individual. Its expression is public.

As we have already indicated, the communication of ideas is very important to scientific inquiry. It is only through communication that we can gain knowledge of the observations and concepts of others, or others can know of our observations and concepts. We must know what others are thinking so that we can continuously correct and extend our scientific knowledge. We have also seen that effective communication depends on similarity of expression among the parties to the communication. It follows that for productive inquiry we must strive for some uniformity of concepts among scientists in a particular field. Yet, we cannot insist on or enforce this uniformity without restricting the freedom of thought which is necessary to the individual's contribution to inquiry. For purposes of communication we desire uniformity of concepts, for purposes of inquiry we must have flexibility. So we treat the current expression of our concepts as if they were absolutely true as long as they serve our purpose. But at any time we may alter the concept or the expression if we feel that to do so will enhance our understanding of our environment.

Definition of terms

The basic concepts of science are expressed by the words and other symbols we use to communicate our ideas. For the purposes of our
present discussion, this body of written material is a book. It is a book because we say it is a book. The word "book" represents a cluster of ideas, a concept, we have about this means of written communication. This particular example coincides with our concept. In another discussion the word book may represent a slightly different concept. When we speak of the Books of the Bible, the word has a somewhat different meaning. Most of the words we use in ordinary discussion have varied meaning depending on how they are used. Our words derive meaning from the context in which they appear.

From the way the word is used, from the context in which it appears, from its function in the discussion, the person with whom we hope to communicate may be able to see what we mean by the word. This we would call a functional definition of the term. The word is defined by its function in the discussion. Of course, we cannot be sure that the other person will understand what we mean. The meaning to him will depend on his meaning for the other words used with the one we are defining. If these words represent a significantly different concept for him than they do for us, the word being defined will have a different meaning. In order that functional definition be clearly understood, it is often desirable to use the word many times in as many different ways as possible so that the meaning is clear.

The nature of this book makes the use of functional definition appropriate. We have used many words such as measurement, inquiry, and definition in ways that we hope have given them meaning for you which is similar to their meaning to us. But in most scientific writing we value rather highly a brief concise style. For brevity, we rely on stipulative definition. We set out as concisely as possible, in words for which the meaning is not in doubt, the meaning of the word we wish to define. We stipulate the meaning of the word. Stipulative definition would be excellent were it not for the difficulty of finding words which are completely unambiguous, words for which the meaning is not open to question. In every stipulative definition we must use words which we may be called upon to define. If we give stipulative definition of these terms, we will have to use words which we may be called upon to define. And so on. Every such attempt at complete definition ends in either a circuity, in which we use words for which we have stipulated the definition to explain that definition, or in an infinite regress, in which we go on forever defining terms we used in previous definition. Again, we must accept less than perfection and look forward for improvement.

There are basically two ways in which we may set forth a stipulative definition. The better, from the point of view of the logician, is the categorical definition. We can give meaning to a word by placing the concept it represents in a larger class of concepts and then stating how it can be distinguished from all other concepts in that class. Our original definition of science is of this type. "Science is a body of knowledge ..." There are many bodies of knowledge some
of which may, according to this definition, be called science. "Science is a body of knowledge organized . . ." The word organized distinguishes science from a jumble of information, but not from a dictionary. "Science is a body of knowledge organized so as to increase man's understanding and use of his environment to improve his way of life." Any body of knowledge which meets these final conditions we would call science.

Categorical definition, while logically sound, suffers particularly from the weakness, previously referred to, of requiring the use of words which may need further definition. To a tropical botanist, "The fruit of the large perennial herb Musa sapientum," might be an adequate definition of the banana. The banana is placed in the category of fruit and distinguished from all other fruit in that it is derived from the species Musa sapientum from which no other fruit is derived. To most of us this might serve as a definition of the species Musa sapientum, but it would be meaningless if we didn't already know what a banana is. Similarly, our definition of science is not particularly meaningful unless we accept some common meaning for such words as knowledge, understanding, and improve.

A second method of setting forth a stipulative definition is to list the elemental ideas which go to make up the concept which we use the word to represent. We can describe or characterize the concept. I might say the banana is relatively long and thin, has a tough yellow skin of medium thickness, with a pulpy central core which is good to eat, having a distinctive flavor similar to amyl acetate and a texture which is soft and free of tough fibers and seeds. This, to some of us, is a more meaningful definition of the banana than the one given previously. A person who had never seen one might pick out a banana from the collection of goods at the grocery by using this definition. This descriptive definition, while less sound logically, would serve him better than the previous one.

A stipulative definition may be categorical, descriptive, or a combination of these. It is often convenient, when setting forth a categorical definition, to use descriptive words to distinguish the concept being defined from others of the same class, or to elaborate the definition. "The banana is the fruit of the perennial herb Musa sapientum, it has a thick tough yellow skin and a pulpy edible core which is free of tough fibers and seeds." The description in this definition is not logically necessary, but it certainly helps to make the definition more meaningful to most of us.

We can also use a statement of analogy for the purpose of definition, if the analog of the concept being defined is well understood. "The plantain is the fruit of the herb Musa paradisiaca, it is like a banana except that it is large and less flavorful and is usually cooked before eating." In this definition the concept expressed by the word banana serves as the analog for the concept we wish to express by the word plantain. We distinguish the plantain from other members of the
class "fruit" by comparing it to the banana and citing some significant differences between the concept being defined and its analogy, telling how the plantain differs from the banana.

We can use analogy in other ways to give definition to the expression of a concept. In the section of this chapter devoted to categorization and classification we will see that many of our concepts are developed through a process of abstracting similarities from among a set of ideas. It is on the basis of these similarities that we see analogy. Similarities also provide a basis for establishing categories and defining classes.

Mathematical and pseudo-mathematical models provide another means of definition. When we write the algebraic formula $d = \frac{m}{v}$, or make the statement "density equals mass divided by volume," we have defined the concept which is expressed by the word density. This statement tells us that we can find the numerical value of the density of a sample of substance by dividing (an operation defined for numbers in the mathematical-deductive system of numerical algebra) the numerical value for the measure of mass by the numerical value for the measure of volume, and we can find the units of density by dividing (an operation defined for units in the pseudo-mathematical system of dimensional and unital analysis) the units of the measure of mass by the units of the measure of volume. The statement $d = \frac{m}{v}$ is a quantitative definition of density. Since the measures of mass and volume are arbitrarily defined by the conventions of measurement, the concept of density thus defined is unequivocal. Quantitative definition of observable characteristics of the environment give to the language of scientific inquiry increased accuracy, just as measurement gives greater accuracy to observation.

Classification and Categorization

A second process by which we develop and modify our concepts, closely related to the process of definition, is the process of classification. The close relationship is easily seen in the categorical definition. If we are to place the expression being defined in a larger class, we must have some concept of this class. The expression we use to communicate this larger concept (larger in the sense that it includes the other) serves as a category into which we may classify the concept for which we use the expression being defined. We might define a category or class as a concept which contains within it (subsumes) a set of simpler concepts. The concepts subsumed under this larger concept (the category or class) have some elements of similarity. These elements of similarity are the ideas which make up the concept being communicated by the expression used for that class or category.

As an example, let us consider an individual named Tom with whom I am acquainted. Tom is a boy I know. I have placed Tom in the class "boys I know." The expression "boys I know" reflects a concept
which is made up of the similarities between Tom and these other individuals. "Boys I know" is the expression of a larger concept which includes many of the elemental ideas included in the concept expressed by the verbal symbol "Tom." "Boys I know" is a class which subsumes "Tom."

Of course, I have many other concepts which subsume my concept of Tom. The concept which I express by the word "boys" includes many of the ideas contained in my concept of Tom. The class "boys" includes the boys I know. "Boys I know" is a subclass of the superclass "boys." We might go on with this. The concept people subsumes boys. "People" is a subclass of the class "animals." "Animals" is subsumed under the class "living things." "Living things" is a subclass of the superclass "material things."

Each of these verbal symbols (Tom, boys I know, boys, people, animals, living things, and material things) expresses a different concept, a different cluster of elemental ideas. Yet many of the ideas expressed by the symbol "Tom" are included in all of them. The concepts expressed by these symbols serve as classes or categories under which we can group concepts which are similar in certain respects to the concept of Tom. The class name is the expression of a concept which could be descriptively defined by the enumeration of the similarities which exist between Tom and all other concepts in that category.

When we use a class name in inquiry or communication, it expresses our recognition of similarities and differences among our observations. Our ideas, our concepts, our observations, are included in or excluded from a particular class on the basis of similarities or differences which we perceive among them. But not all of our concepts can be organized into a single system of classes. My concept of boys and my concept of honor cannot be grouped together in any single superclass (excepting of course the class "concepts"). In any attempt to define a category for purposes of classification, it is imperative that the subclasses be made up of elements which are comparable on some logical basis. Classes must be made up of similar elements. Systems of classification must be organized so that at each level of classification comparable concepts are related.

When we have defined and organized a system of classification, the relationships which exist among classes help us to see relationships among the elements of those classes and to express these relationships in simpler language. In order to see more easily the relationships which may exist between categories, we may make use of a mathematical model taken from the mathematical-deductive system known as Boolean algebra, or the algebra of classes.

One simple relationship which may exist between two classes in the same superclass is that of total inclusion. Our example involving Tom contains several examples of this relationship. All boys I know are
boys. All boys are people (logically at least). All people are animals. The class "boys" totally includes the class "boys I know." The class "boys" is totally included in the class "people." Every element of the former is an element of the latter. In the language of Boolean algebra, if for two classes A and B, $A \cup B = A$ and $A \cap B = B$ we can say that the class A is a subclass of the class B and every element in A is in B. For every such relationship between two classes, there is defined an additional class $(A')$ of those elements in B but not in A. This we would call the complement of A in the superclass B.

The opposite extreme of relationship between two comparable classes is that of total exclusion. The most obvious example of two classes having this relationship is any class and its complement in some superclass. The complement of the class "boys" in the superclass "people" is mutually exclusive with the class "boys." Boys and girls are mutually exclusive (logically at least). If these classes are represented by the symbols B and G respectively, $B \cap G = 0$, there is no element which is in both of these classes. For every pair of mutually exclusive classes (A and B), there can be defined a class $(A \cup B)$ which includes both and within which these classes are complementary.

A third possible relationship which may exist between two comparable classes is that of partial inclusion, in which some, but not all, of the elements of one class are in the second class. In this case each of the union $(A \cup B)$ and the intersection $(A \cap B)$ may be defined as a class in some ways distinct from either A or B.

If we extend these three binary (between two classes) relationships to relationships among more than two comparable classes, an extremely large number of classes, each in some way distinct from all others, may be defined. If three classes A, B, and C each contain some but not all the elements of each of the others, there are six distinct classes logically defined by the binary Boolean expressions $A \cup B$, $A \cup C$, $B \cup C$, $A \cap B$, $A \cap C$, and $B \cap C$. Other classes may be defined by such expressions as $A \cup B \cup C$, $A \cap B \cap C$, $A \cup B \cap C$, etc. Logically, the number of classes which may be defined within any one superclass is limited only by the number of mutually exclusive primary elements and is equal to the number two raised to that power.

For purposes of scientific inquiry, we may define a class or category as any concept which contains within it simpler concepts or elemental ideas which may be considered as subclasses or elements within the larger concept or superclass. The simpler the relation among classes the more effective is their use in the organization and communication of knowledge. Relationship among comparable classes is productive in inquiry through furnishing leads to seeing relationships among elements of these classes.

Two types of relationship among a set of classes are of particular value to inquiry. One of these is the hierarchical series, in which
each category is a subclass of the category following it (or preceding
it) in the series. Our discussion related to my friend Tom is an example
of such a series. If we use the symbols T, K, B, P, A, L, and M for
these classes in the order of their presentation in the discussion, we
can say that $T \leq K \leq B \leq P \leq A \leq L \leq M$. We find many such series in the
literature of science.

The second important simple relationship among a set of classes
is that of mutual exclusion and total exhaustion within a defined super-
class. If all the elements of a set of concepts can be placed in sub-
classes so that every element is in one and only one subclass, we say
that the subclasses are mutually exclusive and totally exhaustive within
that superclass. When we classify persons according to age, we use such
a system. Each individual is properly classified into one and only one
of the consecutive annual age groups. A person is either nineteen, or
twenty, or some other integral age according to this system. No one is
ever properly placed in two age groups at the same time. Other examples
of this type of relationship are seldom so clearly exclusive (this is
another advantage of mathematical models). When we classify all matter
into gas, liquid, and solid, we would like these classes to be mutually
exclusive and totally exhaustive, but unfortunately things do not be-
have in as orderly a fashion as do numbers. Just when we have neatly
classified all matter we are served our gelatin dessert. Is it solid
or liquid? Or we look out at the fog. Is it solid or gas?

Throughout the process of scientific inquiry we design systems of
classification in order to simplify the communication of our concepts
and to enhance the derivation of new ideas. To be effective a classi-
fication system should have the following characteristics: (1) there
should be a defined superclass in which all elements being classified
are elements; (2) elements and subclasses should be comparable on some
logical basis; (3) there should be a set of subclasses such that every
element in any subclass is a member of the defined superclass; (4)
elements should be included in or excluded from any subclass on the
basis of similarity or difference with respect to other elements in
that subclass; (5) definition of all classes and elements involved
should be understandable to the persons using the system. Once again
we must admit that most of the systems which we use fall short of this
goal. We do the best we can and work toward improvement.

Logical Models

In order to identify the objects we observe, we use words and
symbols. Most of the identifying concepts reflected by these symbols
are related to real things, that is, reality as we see it. A tree, a
dog, a house, a book, these are concrete reality. We can illustrate our
concepts by pointing out specific examples which can be observed
directly.
Our concept of air can be illustrated through observation of the ways in which it affects other things. While we cannot see air optically, we can observe the effect of its presence, we can measure its weight, the pressure it exerts, its temperature, etc. Air is as real as the tree or the dog. Even though we cannot see it or feel it (in the usual sense of these words) we are convinced that it is all around us. Air is as much a concrete reality as the house or the book.

Usually when we observe some effect, some change or variation in the environment, we can attribute it so some such concrete reality. The tree is green. The dog barks. I breathe air. By statements such as these I relate my observations to concrete reality. The green light which strikes the optical surfaces of my eye is reflected from the tree. The vibrations which excite my auditory sense emanates from the dog. The feeling I sense in my respiratory organs is due to the passage of air.

But, sometimes our observations cannot be attributed to such readily evident reality. Sometimes it is necessary, in order to explain our observations, to suppose the existence of some concrete system which we cannot observe directly, some different kind of reality. In our desire to understand our observations and to explain the relationships we see among them, we develop an ideational analog and assign it such properties as would produce the observed behavior. These mental constructs we would call logical models.

An example of such a logical model is the molecule. As we observe the properties of matter, the question of its continuity arises. If I take a piece of chalk and break it in two, I have two pieces of chalk. If I break each of these in two, I have four pieces of chalk. If I continue this process I will continuously obtain more and more pieces of chalk which are smaller and smaller. Physically (in the realm of concrete reality), I will soon reach the point at which I can no longer hold one of the pieces and break it, but I can continue to think about what would happen if I were able to do so.

There are two possible conclusions to this mental exercise. Either matter is continuous, in which case I could go forever (ideationally at least) subdividing the successively smaller particles of chalk into still smaller ones; or there is some point in the process at which I would have the smallest possible particle of chalk. In the latter event we would say that chalk is discontinuous.

In the case of chalk I cannot answer the question directly from observation. The smallest particle of chalk which I can observe directly has all the essential characteristics of chalk. If I managed to break it in two, I could no longer observe it directly. When I consider the observed properties of solids and liquids, I might conclude that matter is continuous. If I could continue to subdivide the bits of chalk, I would still have smaller bits of chalk. But, when I observe the behavior of
gases I run into difficulty.

If I open a bottle of some vile smelling chemical in the front of the room, you will soon observe its presence. Somehow the matter from the bottle has diffused through the air in the room and affected your olfactory nerves. If matter is continuous, there must be a continuous stream of this substance from the bottle to you. This I find inconceivable. I cannot imagine how the continuous matter of the substance in the bottle could diffuse through the continuous matter of the air in all directions so that everyone in the room could smell the stuff and still breathe. Therefore, I say that matter is discontinuous; that for any substance there is a least particle which will have the essential properties of that substance. This least particle of a substance I will call a molecule.

My concept of the molecule is a logical model which helps me to explain the observed properties of matter. I have never seen a molecule, yet I am firmly convinced that all matter is made up of molecules because I cannot conceive of continuous matter behaving in ways in which I have observed matter to behave.

Of course, the molecule is not a perfect model. From our observation of changes in matter we must conclude that the molecule cannot explain all our observations. So we develop additional logical models such as atoms, ions, electrons, etc. The atom is a logical model developed to explain observations of changes in matter, but it fails to explain some of the observed changes, so we develop the logical models represented by our concepts of sub-atomic particles to explain these changes. But there are new observations requiring new logical models. Our logical models are always subject to extension, modification or rejection when new observations make this desirable.

Dangers of Conceptual Thought

The words and symbols which we use to organize and communicate our ideas -- the expression of our concepts, our classes, our categories, and our logical models -- make inquiry possible. It is through words and symbols that we communicate our thoughts. It is through the expression of our concepts that we establish the conventional knowledge which is the body of science. It is through the expression of our concepts that we organize thought which is the spirit of science. Yet these words and symbols, these expressions of our concepts, may exert a tyranny over our minds which can stifle inquiry and stunt our scientific growth.

This is a book because we say it is a book. And having said this we have said nothing. The word "book" has no meaning except as it expresses a concept, a cluster of ideas. If we treat the word as if it has existence of its own, it becomes a threat to inquiry. Words and
symbols make communication and inquiry possible. Through communication, our observations become a part of the ongoing process of scientific inquiry. In this process our concepts develop and are modified and extended. Words and symbols affect our thought. But we must be exceedingly careful lest they come to control our thought. The vocabulary of science expresses our ideas of things. But we must be constantly alert to the danger that the vocabulary may come to control the ideas.

The great danger, inherent in conceptual thought, has been called the fallacy of identification. By this we mean the assumption that verbal expression reflects reality. Our words and symbols reflect our concepts, our thoughts derived from uncertain observation by less certain processes of seeing relationship. They represent reality as we see it. The words and symbols used by us and by others do affect the way in which we see reality alter our concepts, but they cannot, of themselves, affect nature as it exists.

Three hundred fifty years ago, Sir Francis Bacon warned us against this danger. He said that if we wished to see nature clearly we must rid ourselves of the "Idols of the Mind" which blind us to reality. The first of these are the Idols of the Tribe, whose worship leads us to "fallacies natural to humanity in general." Here Bacon refers to the tendency of man to see all things in terms of human characteristics. It is the Idols of the Tribe which we bow to when we see the world around us reflect our human qualities, when we see animal intelligence in terms of human behavior, when we interpret our data solely in terms of our human aspirations. These are the Idols who gave mankind anthropomorphic gods and a geocentric universe.

The second group of Idols are the Idols of the Cave, these control the thinking of particular individuals. Some men are by nature analytical and see differences everywhere. Such men will build their concepts, their classes and categories, their logical models, out of words that express diversity. Others are by nature synthetic in thought and see resemblances. Such men use words of unity. When we insist that the relationships of nature fit the patterns imposed by our own personalities, we are worshiping the Idols of the Cave.

The third set of Baconian idols are the Idols of the Market-Place. In the world of commerce, we depend upon language according to the understanding of the crowd, but our ordinary use of language is so inexact, so open to varied meaning that there often "... arises from a bad and inapt formation of words, a wonderful obstruction to the mind." When we adapt the expressions used for the clearly defined, technical concepts of science to the common usage of popular literature and television commercials, we sacrifice them to the Idols of the Market-Place.

"Lastly, there are the idols which have migrated into man's minds from the various dogmas of philosophers, and also from wrong laws of demonstration. These I call Idols of the Theatre, because
in my judgment all the received systems of philosophy are but so many stage-plays, representing worlds of their own creation after an unreal and scenic fashion.... And in the plays of this philosophic theatre you may observe the same thing which is found in the theatre of the poets, -- that stories invented for the stage are more compact and elegant, and more as we wish them to be than true stories out of history.  

Our concepts, and the symbols which we use which reflect these concepts are the basic stuff from which we fashion inquiry. We may, for the purposes of communication, act as if the words we use and the concepts they express were absolutely descriptive of reality. But we must always be on our guard to insure that these ornaments of the mind do not, like the golden ornaments of the Children of Israel, rise out of the fire of inquiry like the golden calf, as Idols which control the direction of our thoughts.

Summary

For purposes of communication we must use words and symbols. The word represents a cluster of ideas which we call a concept. In order that we may make clear the concept expressed by the symbol or word, we define it. The definition of a word may be implied by the way in which the word is used, by the context in which it appears. This we would call functional definition. The definition may be stipulated; that is, we may set forth our meaning for the word, as concisely as possible, by use of other words and symbols which have a common meaning. A stipulative definition may be categorical, or descriptive, or a combination of these.

Definition of a word or symbol will always depend on the meaning of the words used in the definition. Unless these words have similar meaning for all concerned, the meaning of the word being defined will be different for different people. For purposes of communication we would like to have uniformity of concepts and expression. Yet, inquiry depends on a continuous modification and growth of concepts. For purposes of inquiry, we need flexibility of meaning for our words. In order to escape this dilemma, we treat our concepts as if they represented "truth" but stand ready to accept modification of that truth when inquiry requires it.

In order to organize our observations so that they may be most productive in inquiry, we define classes and categories based on similarities and differences which we see among the things we observe. The relationships which exist among classes help us to see relationships among our observations. Models drawn from the mathematical-deductive system of Boolean algebra help us to see relationship among classes.

It is often helpful for us to develop a mental construct which, if it were to exist and have the properties which we assign to it, would explain our observations. This we would call a logical model. The concepts of the molecule, the atom, and the sub-atomic particles are examples of logical models.

Definition and classification of our concepts help us to communicate and organize our ideas, but we must be constantly alert to the danger that our words can control our thoughts. We must always remember that our words are expressions of our concepts, our concepts are our ideas of the environment as we see it from our observation, and observation is always uncertain. From this it follows that our verbal expressions cannot express reality. While we may use our concepts and their expression as if we believed them to be absolutely "true," we must always be willing to accept modification of this truth when the advancement of inquiry shows such modification to be productive.
CHAPTER V

THE DEVELOPMENT OF GENERAL PROPOSITIONS

Summary

Basic ideas are organized into concepts. These concepts are organized in our thinking into conceptual schemes. The expression of a conceptual scheme we call a general proposition. General propositions are known by various names. Laws, theories, and hypotheses are examples of general propositions. The name we give a particular general proposition depends on the way in which it is developed, the extent of empirical evidence which supports it, and its function in the process of inquiry. Regardless of what we may call it, a general proposition serves as the initial premise in the deductive process by which we develop explanation and prediction. To the extent that the proposition is an accurate analog of the reality of the system of the environment under discussion, the explanation is "true" and the prediction is found to be valid when subjected to an experimental test.

Since our conceptual schemes are developed from observation and derived by a process of induction, they must always be regarded as containing a large element of uncertainty. Our propositions are never true in the absolute sense. If a proposition is reasonable, understandable, and productive, it is retained in the system of thought. If not, it is modified or rejected. We say that there are three criteria for judging a proposition: the logical, the semantic, and the pragmatic. But the evaluation must be made on a relative, rather than an absolute basis. Since no perfect system of logic exists, no perfect language has been yet developed, and no one has complete prescience, we must make our judgment in terms of a choice among the several available propositions. The proposition which is most reasonable in our system of thought, most easily understood by us, and most productive of further inquiry is the one which we retain and use.
CHAPTER VI

SCIENTIFIC METHODOLOGY

Summary

Scientific inquiry, as an ongoing process of the human mind, may be described in several ways. Writers in the philosophy of science present various descriptions of "The Scientific Method." Perhaps the best known is the set of four propositions set forth by Newton which have come to be known as the doctrine of sufficient reason. This model, while useful in many ways in guiding inquiry, does not give a full picture of the process.

Other descriptions provide useful models from which we can see the development of scientific thought. The formal model of the inductive-deductive cycle shows one way in which concepts and conceptual schemes may be developed and their symbolic expressions defined. The hypothetico-deductive-observational model for empirical science illustrates the process for validation of a proposition through experimental observation.

Probably the most productive descriptions of scientific methodology are those related to the process of problem solving. Formal problem solving consists of six steps: comprehension, analysis, evaluation, synthesis, solution, and check. Any problem which can be solved by the formal methods of symbolic logic, mathematics, and formal semantics can be solved effectively by application of this method. If the problem cannot be solved because of lack of information, the missing items of information can be identified by the application of this model. Problems of less formal nature may be approached by a process of successive approximation in which an hypothesis is proposed and subjected to experimental test. The observations made in the testing of one hypothesis are used in arriving at a new hypothesis which is then tested. And so on. The process can be continued until a satisfactory solution of the problem is found. When a solution to the immediate problem has been found, it should lead us to the identification of new problems. In this way inquiry is seen as a continuous process of growth in the understanding and utilization of man's environment to improve his way of life.

Each description of scientific methodology is helpful in developing understanding of the way in which the individual builds his knowledge. Yet no one model can serve as a complete analog for "The Scientific Method." Each of the models presented is limited in some way. We must not allow any one model of methodology to limit our understanding of science as a system of inquiry.
CHAPTER VII
THE STRUCTURE OF RESEARCH

Summary

In order that the total body of scientific knowledge may continue to develop, it is necessary that individual inquiry be set in a framework of research. Essential to this body of research is the existence of a body of critical literature. Criticism provides a process for the verification of this knowledge.

There are basically three rules of criticism: (1) criticism must be directed to the substance of the proposition or to its supporting argument, (2) criticism must be based on apparent logical inconsistency or empirical counter-evidence, (3) the person making the criticism must propose an alternative to the proposition being criticized.

It is through the process of publication and criticism that scientific knowledge develops and is verified. Since the rules of criticism require that some alternative be proposed for every proposition criticized, progress in research is guaranteed.

The first step in research is the selection of a problem. Problems may arise from the study of the present knowledge and present practice in the field through identification of those areas in which significant questions arise. Repetition and elaboration of current research activities may provide significant problems. Problems may arise as "off shoots" of current research. Knowledge of the literature in the field is a primary prerequisite to the identification of significant research problems in any area of inquiry.

When a problem has been identified, it must be judged as to its significance and feasibility. The criteria for judgment include intrinsic criteria, involving the interest and ability of the investigator in his present position; and extrinsic criteria, involving the relationship of the problem to the body of scientific knowledge and the overall process of research. If the problem is judged to be of significance and within the power and ability of the investigator in his present position, it is worthy of research.

The second step in the process of research is the review of the literature. A thorough review of the literature is necessary to avoid unproductive duplication and conflict in research. The review of the
literature is becoming more difficult with the rapid expansion of published knowledge. It is becoming ever more necessary to assign much of the activities of the search of the literature to the research librarian who is a specialist in that area.

When the review of the literature is completed, the investigator can proceed with the execution of the research. There are basically five operational steps: (1) the analysis of the problem; (2) the planning of procedures for the collection of data; (3) the collection of the data; (4) the interpretation of the data; and (5) the drawing of conclusions. Each step has its established methods. The investigator has some freedom in the application of accepted methods, but the development of new methods is a significant problem in itself. Use of new methods must wait their evaluation.

Before a new procedure for research will be accepted, it must be shown to be reliable and valid. The reliability of a procedure is a measure of the extent to which it gives reproducible results. The validity is a measure of the extent to which it does what it proposes to do.

The final step of research is the writing of the report. The report should present the goal of the investigation, the conclusion reached, and the evidence on which the conclusion is based. Brevity and concise style are required in a good research report.

In research report writing, there are strict formal style requirements. These include the form of presentation, strict adherence to formal rules of grammar and punctuation, proper use and form of citation of sources, and a complete bibliography in acceptable form. Since style requirements vary from one field of inquiry to another, it is advisable for the writer of a report to obtain and use a style manual or style sheet acceptable to the editors of journals in the area of knowledge in which he will be involved.

In writing the report, the rules of criticism should be kept in mind. The report should be internally consistent, consistent with accepted conventional knowledge, and give empirical evidence in support of the conclusion. Above all, the report must reflect a scrupulous intellectual honesty.
CHAPTER VIII

THE CLASSIFICATION OF SCIENTIFIC KNOWLEDGE

Conclusions

In the analysis of our conventional scientific knowledge we find, as in any attempt at complete analysis, that our categories and subclasses overlap to such an extent that it is impossible to distinguish distinct areas of inquiry. The accepted categories must be arbitrarily defined. Chemistry is whatever the chemist does. When the gas laws are used by the chemist to explain the stoichiometry of gaseous reactions, they are part of the knowledge of chemistry. They are not exclusively physics. When the identification of the amino acids is used to develop understanding of the structure of the substances which control the genetic order of reproduction, it is a technique of biological research. It is no longer the personal property of the chemist.

New areas of specialization arise as problems of understanding and utilization of the environment lead to the development of new knowledge, new apparatus, and new techniques of research. Development of a new concept (or modification of an old concept) may open new questions leading to the extension of inquiry in a particular direction. A new discipline is born. A new process may provide a new material for man's use and a new technology develops. New apparatus makes possible new techniques, new techniques open new questions, new questions lead us to new goals. It is impossible to catalog the specializations of science, they change too rapidly. The terms we use and the models we design help to give us some understanding of the organization of science, but we must be sure that they do not serve to limit this understanding.

The sphere of knowledge is not smooth and solid. It has prominences which make the Himalayas look like mole hills. It has depressions which, in proportion, make the Milwaukee deep appear as a drainage ditch. Man's knowledge of his environment is so extensive and so diverse that any attempt to fit it in a finite classification system is doomed to failure. To attempt to judge the relative significance of any particular portion of this knowledge is presumptuous to say the least. Yet it is the task of those of us involved in general education at the college level to set out that portion of human knowledge with which every "educated person" should be acquainted.

In the area of the natural science this is particularly difficult. To any scientist, all scientific knowledge is highly significant. To the non-scientist, no particular portion of this scientific knowledge is
of critical importance. A person can use the products of science and technology with little or no understanding of their origin or their function. The often heard remark to the effect that in a democratic society sensible application of the products of science for the general good of man depends on a general understanding of scientific knowledge, is difficult to support. One does not need to be able to design an atom bomb to know its destructive potential. We can accept the data from Hiroshima. Understanding of the mechanism of genetic damage from radioactive fallout is not prerequisite to fear of the results of uncontrolled nuclear weapons testing. On the other hand, a rather widespread knowledge of the principles involved in the structure and operation of the internal combustion engine has not been effective in reducing the annual traffic toll.

What, then, should the educated non-scientist know of science? One answer to this question which has been proposed it to identify those universal propositions which are basic to the broad spectrum of scientific knowledge and to show how these are developed and applied. One difficulty with this proposal is in the identification of these fundamental principles. Each specialist tends to feel that the knowledge of his speciality is fundamental and, in most cases, can support this conclusion by rational argument. Most lists of "basic concepts of science with which every educated person should be acquainted," are too extensive to be functional as the basis for designing a program of general education in the natural science.

Further difficulty is encountered in the problem of determining the depth to which the development of principles should be studied and the extent to which their application should be followed up. Because of the inter-relatedness of all scientific knowledge, it is possible to move from any one point in the body of knowledge to any other by a logical tracing of development and application of principles. Through careful study of the development and application of a few general principles, the whole of present scientific knowledge could be covered.

Finally, we must recognize that conventional scientific knowledge is transient. The system of inquiry by which our present knowledge has been developed will, in all probability, bring about the modification or displacement of any principles which we may now regard as fundamental. There is no present scientific knowledge of which we can say, "This is unalterably and finally true." We must always anticipate that "This, too, shall pass away."

It is hoped that this presentation of science as a system of inquiry, this book and the course for which it is designed, will give the college student a basis for understanding the nature of conventional scientific knowledge, so that he may see more clearly the significance of science in development of all that man is. And that from this base of understanding, the detailed study of any particular segment of man's conventional knowledge may lead to a deeper appreciation of the function of scientific thought in modern society.


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ARTICLE VII

THE DEVELOPMENT OF A BROAD CONCEPTUAL SCHEME:
THE KINETIC MOLECULAR THEORY

In order to develop a logical model which can be used to explain the observed behavior of matter, we must start with our general observation of how things behave. Throughout the recorded history of human inquiry, men have recorded their observations and impressions of the behavior of matter. Solids and liquids may move or be moved but the mass and volume do not seem to change in the process. From observation of this movement we may get some ideas about motion and its causes, but the constant density of such samples of matter seems to indicate a relatively fixed structure. If we wish to develop a logical model for the structure of matter we find it more productive to work from our observation of gases.

From general observation of gases it would seem that we might productively study the relationship of the temperature, the pressure, and the volume of a confined sample of gas. If we are to set up, in the laboratory, apparatus and instruments by which we can measure the effect on one of these variables of specific variations of the other two, data such as those in Table I might be collected. From the data at any particular temperature, we may develop the relationship known as Boyle's law; the mathematical relationship between the pressure and the volume of a confined sample of gas at constant temperature. This relationship may be developed from the data at any particular temperature in any one of several ways using mathematical models from one of several mathematical systems.

Using a model from the system of Cartesian geometry, we can make a graph of the data at 100°C as in Figure 1. A curve of this form is called a rectangular hyperbola. In the Cartesian system, it can be represented by an algebraic equation of the form \( V = \frac{k}{P} \) in which \( V \) is the volume of gas in liters, \( P \) is pressure in mm of Hg, and \( k \) is a constant of proportionality whose value depends on the temperature, the quantity of gas, and the units of volume and pressure. In this case, \( k \) is the constant 24850 L mm of Hg. This relationship may also be expressed in the form of a proportion as \( \frac{V_1}{P_1} = \frac{V_2}{P_2} \) in which \( V_1 \) and \( P_1 \) are the volume and pressure at which one volume is measured, and \( V_2 \) and \( P_2 \) are the volume and pressure at which a second measurement is made.
Table 1

Volume Associated with Various Pressures and Temperatures in a 21.4 gram Sample of Neon

<table>
<thead>
<tr>
<th>Pressure (mm of Hg)</th>
<th>-100°</th>
<th>-50°</th>
<th>0°</th>
<th>50°</th>
<th>100°</th>
<th>150°</th>
<th>200°</th>
<th>300°</th>
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</thead>
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<tr>
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<td>116.0</td>
<td>148.8</td>
<td>182.4</td>
<td>216.0</td>
<td>248.5</td>
<td>282.5</td>
<td>316.0</td>
<td>344.0</td>
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<tr>
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<td>58.0</td>
<td>74.4</td>
<td>91.2</td>
<td>108.0</td>
<td>124.3</td>
<td>141.4</td>
<td>158.0</td>
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<td>49.6</td>
<td>60.8</td>
<td>72.0</td>
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<td>94.4</td>
<td>105.3</td>
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<td>45.5</td>
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<td>43.2</td>
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<td>56.6</td>
<td>63.2</td>
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<td>24.8</td>
<td>30.4</td>
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<td>21.2</td>
<td>26.1</td>
<td>30.8</td>
<td>35.6</td>
<td>40.5</td>
<td>45.1</td>
<td>54.9</td>
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<td>35.4</td>
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<td>23.6</td>
<td>26.3</td>
<td>32.0</td>
</tr>
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<td>14.0</td>
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<td>21.8</td>
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<tr>
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<td>8.3</td>
<td>10.6</td>
<td>13.0</td>
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<td>22.6</td>
<td>27.4</td>
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<tr>
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<td>14.4</td>
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<td>15.5</td>
<td>17.7</td>
<td>19.7</td>
<td>24.0</td>
</tr>
</tbody>
</table>

*These data were artificially designed to fit the needs of this article. Similar data might be derived from observation with proper apparatus.*
Fig. 1 - Cartesian Plot of Volume vs Pressure at 100°C for a 21.4 gm Sample of Neon.
The relationship may also be derived through the use of a model from the mathematical system for the calculus of infinitesimals. The inverse relationship evident in the data at any particular temperature, (the larger the pressure, the smaller the volume) suggests that the difference between successive volume measurements, when divided by the difference between the corresponding reciprocals of the pressure measurements (\(\Delta V/\Delta(1/P)\)) might be constant. In which case we can make certain differential statements about the data.

Table 2 shows these differential data. It will be noted that the values in the \(\Delta V/\Delta(1/P)\) column are relatively constant. (By use of the mean as the measure of central tendency and the mean deviation as the measure of variability, the percent uncertainty is less than one percent.)

If we assume that the relationship between volume and pressure has certain regular properties defined in the system of the calculus of infinitesimals, we may say that equal increments in the reciprocal of the pressure is accompanied by equal increments in the volume. In the terminology of this calculus, we say the derivative of volume with respect to the reciprocal of the pressure is a constant, symbolically this is written as \(\frac{dV}{d(1/P)} = k' = 31438 \pm 303\). For most purposes it is within the accuracy of the data and convenient to use the median value (equal to the modal value) of 31600 L mm of Hg for the value of \(k'\).

From this statement we can derive, by use of the process of integration, which is defined by our mathematical model, the algebraic statement \(V = k'/P + C\); in which \(V\) is the volume, \(P\) is the pressure, \(k'\) is the constant of proportionality equal to 31600 L mm, and \(C\) is a constant of integration. By substituting data from one measurement we can show that \(C = 0\); \(V = 316.0\) L, \(P = 100\) mm of Hg; substituting, we get \(316.0 = 31600/100 + C\); \(316.0 = 316.0 + C\); \(C = 0\). If we substitute other values of \(V\) and \(P\), the value of \(C\) will always be very close to zero. We can in this way, using a model from the mathematical system of the calculus of infinitesimals, derive the identical relationship \(V = k'/P\) or \(\frac{V_1}{V_2} = \frac{P_2}{P_1}\). Since we arrive at identical statements by two different methods, we may assume this to be a reasonably accurate reflection of the data from which it is derived.

Before we accept this statement as a general empirical law however, we should test its applicability to our other data and to other data collected from observation of samples of other gases. If the statement is found to be applicable to other such data, with a reasonable degree of accuracy, we may accept it as a general empirical law.
### Table 2

Differential Analysis of P-V Data at 200°C.

<table>
<thead>
<tr>
<th>$\Delta V$</th>
<th>V</th>
<th>P</th>
<th>1/P</th>
<th>$\Delta (1/P)$</th>
<th>$\Delta V/\Delta (1/P)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>158.0</td>
<td>316.0L</td>
<td>100 mm</td>
<td>0.100</td>
<td>0.005</td>
<td>31600 L mm of Hg</td>
</tr>
<tr>
<td>52.7</td>
<td>158.0</td>
<td>200 mm</td>
<td>0.0050</td>
<td>0.00167</td>
<td>31600</td>
</tr>
<tr>
<td>26.5</td>
<td>105.3</td>
<td>300 mm</td>
<td>0.00333</td>
<td>0.00083</td>
<td>31600</td>
</tr>
<tr>
<td>15.6</td>
<td>78.8</td>
<td>400 mm</td>
<td>0.00250</td>
<td>0.00050</td>
<td>31200</td>
</tr>
<tr>
<td>10.5</td>
<td>63.2</td>
<td>500 mm</td>
<td>0.00200</td>
<td>0.00033</td>
<td>31800</td>
</tr>
<tr>
<td>7.6</td>
<td>52.7</td>
<td>600 mm</td>
<td>0.00167</td>
<td>0.00024</td>
<td>31600</td>
</tr>
<tr>
<td>5.6</td>
<td>45.1</td>
<td>700 mm</td>
<td>0.00143</td>
<td>0.00018</td>
<td>31200</td>
</tr>
<tr>
<td>4.4</td>
<td>39.5</td>
<td>800 mm</td>
<td>0.00125</td>
<td>0.00014</td>
<td>31400</td>
</tr>
<tr>
<td>3.5</td>
<td>35.1</td>
<td>900 mm</td>
<td>0.00111</td>
<td>0.00011</td>
<td>31800</td>
</tr>
<tr>
<td>2.9</td>
<td>31.6</td>
<td>1000 mm</td>
<td>0.00100</td>
<td>0.000090</td>
<td>32200</td>
</tr>
<tr>
<td>2.4</td>
<td>28.7</td>
<td>1100 mm</td>
<td>0.000910</td>
<td>0.000076</td>
<td>31600</td>
</tr>
<tr>
<td>2.0</td>
<td>26.3</td>
<td>1200 mm</td>
<td>0.000834</td>
<td>0.000064</td>
<td>31200</td>
</tr>
<tr>
<td>1.7</td>
<td>24.3</td>
<td>1300 mm</td>
<td>0.000770</td>
<td>0.000055</td>
<td>30900</td>
</tr>
<tr>
<td>1.5</td>
<td>22.6</td>
<td>1400 mm</td>
<td>0.000715</td>
<td>0.000048</td>
<td>31300</td>
</tr>
<tr>
<td>1.3</td>
<td>21.1</td>
<td>1500 mm</td>
<td>0.000667</td>
<td>0.000042</td>
<td>32300</td>
</tr>
</tbody>
</table>

$\Delta V/\Delta (1/P)$: Mean = 31438; Mean deviation = 303; % deviation = 0.96%. Mode = 31600. Median = 31600.
One way to design such a test would be to use the principles of the algebra of numbers to derive a statement of relationship which is consistent with the law and which can be easily tested. If \( V = \frac{k}{P} \) for any sample of gas at a particular temperature, \( V_1 = \frac{k_1}{P_1} \) for a particular sample of gas at constant temperature, and \( V_1 P_1 = k_1 \). Thus, for any sample of gas at a particular temperature the product of the pressure times the volume should be constant through any changes of pressure and volume. Table 3 (page 136) shows how well the data taken at other temperatures agree with this conclusion. It can be seen that these data agree with Boyle's law to within two tenths of one percent, when the uncertainty is judged in terms of the mean deviation.

It should be noted that the data used in this discussion are artificially derived for the purposes of this article. Careful observation of a sample of neon might give data with this accuracy. For most other gases, data having this accuracy would probably not be obtained even with the best possible apparatus, the most accurate instrument, and the greatest care in their use.

Having established a reasonably accurate general statement of relationship between volume and pressure at constant temperature, we may proceed to derive a statement of relationship between another pair of variables. To find the relationship between the volume and the temperature when the pressure is constant, we can use the data from Table 1 at any particular pressure (such as 500 mm of Hg) and make a graphic interpretation. When these data are plotted according to the system of Cartesian geometry, we obtain a straight line as in Figure 2, page 137. Within the Cartesian system, a straight line may be represented by an equation of the form \( V = mt + b \), in which \( V \) is the volume, \( t \) is the centigrade temperature, and \( m \) and \( b \) are constants depending on the size of the sample, the pressure and the units of volume and temperature.

If we substitute the values of \( V \) and \( t \) at two of the points on the line, \((V = 23.2 \, \text{L}, \, t = -100^\circ \text{C}; \, \text{and} \, V = 76.9 \, \text{L}, \, t = 300^\circ \text{C})\) into the general form \( V = mt + b \), we can obtain two equations in \( m \) and \( b \) \((23.2 = -100 \, m + b, \, \text{and} \, 76.9 = 300 \, m + b)\) which can be solved simultaneously by use of the principles from the algebra of numbers to give the values of the constants \( m \) and \( b \) for these data: 23.2 = -100 \, m + b.

\[
\begin{align*}
\text{b} &= 23.2 + 100 \, m \\
\text{substitute for b in} & \quad 23.2 = -100 \, m + b \\
76.9 &= 300 \, m + b \\
76.9 &= 300 \, m + 23.2 = 100 \, m \\
53.7 &= 400 \, m \\
0.134 &= m
\end{align*}
\]

Then \( V = 0.134 \, t + 36.6 \), is a general equation reflecting these data.
Table 3
PV Product for Data from Table 1

<table>
<thead>
<tr>
<th>Temperature in °C.</th>
<th>-100</th>
<th>-50</th>
<th>0</th>
<th>50</th>
<th>100</th>
<th>150</th>
<th>200</th>
<th>300</th>
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</thead>
<tbody>
<tr>
<td>Pressure in mm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>100</td>
<td>11600</td>
<td>14880</td>
<td>18240</td>
<td>21600</td>
<td>24850</td>
<td>28250</td>
<td>31600</td>
<td>38400</td>
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<td>200</td>
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<td>38400</td>
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<td>38400</td>
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<tr>
<td>500</td>
<td>11600</td>
<td>14900</td>
<td>18250</td>
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<td>24900</td>
<td>28300</td>
<td>31600</td>
<td>38450</td>
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<td>31570</td>
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<td>24960</td>
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<td>38400</td>
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<td>18270</td>
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<td>38430</td>
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<td>31570</td>
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<td>21600</td>
<td>24800</td>
<td>28320</td>
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<td>21591</td>
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<td>28294</td>
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<tr>
<td>Δ</td>
<td>20</td>
<td>20</td>
<td>23</td>
<td>7</td>
<td>33</td>
<td>13</td>
<td>21</td>
<td>32</td>
</tr>
<tr>
<td>% Δ</td>
<td>0.17%</td>
<td>0.13%</td>
<td>0.13%</td>
<td>0.03%</td>
<td>0.13%</td>
<td>0.05%</td>
<td>0.07%</td>
<td>0.08%</td>
</tr>
</tbody>
</table>
Fig. 2 - Cartesian Plot of Volume vs Temperature at 500 mm of Hg Pressure.
If we assume a similar linear relationship exists between volume and temperature at other pressures, we may solve similar sets of equations at each pressure. The several values of \( m \) and \( b \) at various pressures appear in Table 4.

**Table 4**

**Linear Constants for Equation** \( V = mt + b \) **at Various Pressures**

<table>
<thead>
<tr>
<th>Pressure</th>
<th>( m )</th>
<th>( b )</th>
<th>( b/m )</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>0.664</td>
<td>182.4</td>
<td>274</td>
</tr>
<tr>
<td>200</td>
<td>0.332</td>
<td>91.2</td>
<td>273</td>
</tr>
<tr>
<td>300</td>
<td>0.222</td>
<td>60.8</td>
<td>273</td>
</tr>
<tr>
<td>400</td>
<td>0.165</td>
<td>45.5</td>
<td>274</td>
</tr>
<tr>
<td>500</td>
<td>0.134</td>
<td>36.6</td>
<td>274</td>
</tr>
<tr>
<td>600</td>
<td>0.111</td>
<td>30.4</td>
<td>274</td>
</tr>
<tr>
<td>700</td>
<td>0.096</td>
<td>20.3</td>
<td>272</td>
</tr>
<tr>
<td>800</td>
<td>0.082</td>
<td>22.7</td>
<td>276</td>
</tr>
<tr>
<td>900</td>
<td>0.074</td>
<td>20.3</td>
<td>257</td>
</tr>
<tr>
<td>1000</td>
<td>0.066</td>
<td>18.2</td>
<td>276</td>
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<tr>
<td>1100</td>
<td>0.061</td>
<td>16.6</td>
<td>272</td>
</tr>
<tr>
<td>1200</td>
<td>0.055</td>
<td>15.2</td>
<td>276</td>
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<td>271</td>
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</tbody>
</table>

From Table 4 it can be seen that both \( m \) and \( b \) vary widely with pressure. It would be convenient if we could develop a relationship which would not involve any such term as \( b \). By use of the algebra of numbers, we can change the form of the equation \( V = mt + b \) to the equivalent expression \( V = m(t + b/m) \). The right hand column of Table 4 shows that the value of \( b/m \) is relatively constant. (Mean \( b/m = 273 \), mean
deviation = 2, % deviation = 0.73%). If we add this constant value (273) to the centigrade temperature, we can establish a new temperature scale. This scale of temperature measurement is called the Kelvin scale or the absolute temperature scale. If the temperatures are expressed in this absolute scale, the relationship of volume to temperature at constant pressure may be expressed by the equation \( V = nT \) in which \( V \) is volume, \( T \) is absolute temperature, and \( n \) is a constant of proportionality whose value depends on the pressure, the quantity of gas, and the units of volume. Verbally, "For a confined sample of gas at constant pressure, the volume is directly proportional to the absolute temperature," is known as Charles' Law in honor of the French scientist of the eighteenth century who first reported the relationship. This relationship may also be expressed by the proportion \( \frac{V_1}{V_2} = \frac{T_1}{T_2} \).

Having established these "laws" for the behavior of gases, in terms of the relationships between pressure and volume at constant temperature, and between temperature and volume at constant pressure, it would be convenient if we could derive a "combined law" through which the relationship among the three variables could be expressed in a single equation. This can be done most elegantly through the use of partial differential equations from the calculus of infinitesimals. The solution can be seen graphically if a plot of the \( PV \) product vs absolute temperature is made. Figure 3 presents this curve. This relationship may be expressed by the equation \( PV = nRT \) in which \( P, V, \) and \( T \) represent the variables, \( n \) represents the quantity of gas in the sample, and \( R \) is a universal gas constant. The value of \( R \) is the same for all gases. Its value depends on the units of \( P, V, T, \) and \( n \).

These empirical laws, Boyle's law, Charles' law and the combined laws, describe the observed behavior of gases. These statements of observed relationship, together with several other empirical laws of gaseous behavior, summarize the data which has been obtained from careful observation of these elements of the environment. If we wish to explain this behavior, we must develop a logical model which would, if it were to exist, have these properties. With such a model as the beginning point, we may build a broad conceptual scheme which will explain this observed behavior of gases.

If we are to derive an ideational model with which to explain our laws, we must start by making some assumptions. The first of these assumptions is the molecular hypothesis.

If we consider the question of the continuity of matter, we can come to either of two possible conclusions. If matter is continuous, we could (ideationally at least) take any sample of matter and break it into succeedingly smaller portions which would retain the essential properties of that substance. The alternative conclusion is that there is some least particle of any substance which cannot be broken into smaller portions without loss of essential properties. In this case we would say that matter is discontinuous.
We cannot answer this question directly from observation because it is physically impossible to subdivide a homogeneous sample of matter into small enough portions and observe the results. We must assume one of the alternatives to be true, and then by the process of deduction from this assumption, we may test the validity of the assumption by comparing the conclusion reached with our observation.

While observation of solids and liquids might support the assumption of continuous matter, the behavior of gases leads us to accept the alternative assumption of discontinuity. Therefore, let us assume that all matter is made up of extremely small particles, which we will call molecules. A molecule is the least part of a substance which retains the essential properties of that substance. Let us assume also that molecules of the same substance are alike in all respects, and that molecules of different substances are different in some essential way.
This assumption is called the molecular hypothesis. It is an assumption made for the purposes of discussion and inquiry. As long as it helps us we will retain it. When it fails us we will alter it or discard it.

A second convenient assumption is that the same laws which describe the motion of observable particles apply to these molecules. Since we cannot observe these particles, it follows that we cannot directly observe their motion. If we assume that they behave the same way as observable particles we may better understand the behavior of matter. If at any time the structure of thought which we build from this assumption leads us to predictions which are not borne out by our observation, we will alter or discard the assumption.

From these two assumptions we can set forth a logical model which we may use as an analog for the structure of gases. Through the use of this model we may improve our understanding of the behavior of gases. The model can be defined by setting out four postulates:

Postulate 1: All matter is made up of particles called molecules defined by the molecular hypothesis.

Postulate 2: These molecules are in constant, rapid, random motion with the average kinetic energy of the molecules in any sample dependent on the temperature.

Postulate 3: All collisions between molecules are perfectly elastic, no kinetic energy is lost in collision. (A corollary to this postulate is that there are no attractive forces between molecules).

Postulate 4: The volume of the molecule itself is negligible with respect to the volume it effectively occupies.

This model for the structure and behavior of gases is called the Kinetic Molecular Theory. It is possible for us to accept this model because, on the basis of the molecular hypothesis and the assumption of the extension of the laws of motion to minute particles, the model helps us to explain the laws of gaseous behavior which we have developed from observation.

We can explain the pressure exerted by a sample of gas in terms of the force exerted on the sides of the container by the molecules of the gas colliding with the wall of the container. Let us consider a sample of gas containing a number of molecules (n), each having a certain mass (m), contained in a cubic container having a length (L) for each edge. When a moving object strikes another object, it exerts a force equal to the change in its momentum (Δmv; m is mass, v is velocity). If a molecule moving in a line perpendicular to the surface of one face of the container strikes that surface, it rebounds along the same path in the opposite direction. Postulate three stipulates that no energy is lost in such collisions. Thus, the force exerted by each such
collision is equal to the change in momentum from \( +mv \) to \( -mv \), a change of \( 2mv \). If the molecule were to travel unimpeded to the face opposite and return, it would travel a distance of \( 2L \) (\( L \) is the distance between opposite faces of the cubic container), before striking that face again.

If the motion of the molecules is statistically random, as stipulated in postulate two, it can be shown by use of a model from the field of mathematical statistics that the total effective motion of all the molecules can be analysed into three equal components perpendicular to each other. Each component may be represented by one third of the molecules in the sample (\( n/3 \) molecules) moving perpendicular to opposite faces of the cubical container, all having a velocity equal to the square root mean square velocity of all the velocities. (This is the average velocity referred to in postulate two).

Each of the \( n/3 \) molecules traveling perpendicular to one of the faces will, in one unit of time, have \( v/2L \) collisions with that face. Since each collision exerts a force equal to \( 2mv \), the total force on that face will be \( n/3 \times v/2L \times 2mv \). This expression equals \( nmv^2/3L \). (\( n/3 \times v/2L \times 2mv = nmv^2/3L \)). We can say that the force (\( F \)) on one face of the container may be expressed as \( F = nmv^2/3L \).

Since pressure is defined as force per unit area (\( P = F/L^2 \)) we can show that \( P = nmv^2/3L^2 \). But \( L^3 \) is the volume (\( V \)) of the container in which the gas is confined. Therefore, \( P = nmv^2/3V \) or \( PV = nmv^2/3 \). This is equivalent to one of the forms of Boyle's law if \( nmv^2/3 = k \). This model (the kinetic molecular theory) explains Boyle's law since the number of molecules in the sample (\( n \)), the mass of each molecule (\( m \)) does not change for a given sample of gas, and the average velocity (\( v \)), according to postulate two, depends on temperature which must be constant if Boyle's law is to apply.

Now let us consider the case in which the temperature may change while the pressure remains constant. According to postulate two, the average kinetic energy of a molecule (\( 1/2mv^2 \)) is proportional to the absolute temperature. We may express this relationship by the equation \( 1/2mv^2 = CT \), in which \( T \) is absolute temperature and \( C \) is a constant of proportionality. If we multiply both sides of this equation by \( 2/3V \), we get an equivalent statement, \( mv^2/3V = 2/3CT/V \) for one molecule. For the \( n \) molecules in the sample, \( nmv^2/3V = 2/3CT/V \). But according to our previous development, \( nmv^2/3V = P \). Therefore, we can say that \( P = 2/3CT/V \), or \( V = (2C/3P)T \). But 2, 3, and \( C \) are all constants and we have stipulated that the pressure (\( P \)) is to remain constant throughout the process under discussion. Therefore, \( 2C/3P \) is a constant which we may represent by the symbol \( m \). The statement now becomes \( V = mT \) which is the same as the equation, derived from empirical data, which we called Charles' law.
Let us make the additional assumption that equal volumes of gases at the same conditions of temperature and pressure contain the same number of molecules regardless of what gas is observed.¹ We can define a constant \( R = \frac{2C}{3n} \) in which \( C \) is the proportionality constant in the equation \( \frac{1}{2} nmv^2 = CT \) and \( n \) is the number of molecules in a sample of any gas having volume \( V \) at pressure \( P \) and temperature \( T \). This equation \( \frac{1}{2} nmv^2 = CT \) may then be written \( \frac{1}{3} nmv^2 = RT \). Combining this with the equation \( PV = \frac{nmv^2}{3} \), we can derive the equation \( PV = nRT \) in which \( n \) represents the number of molecules (usually expressed in moles) and \( R \) is a universal constant, the same for all gases. Thus, we have derived, from the kinetic molecular theory, the same statement as the empirically derived combined gas law.

Through similar development of the mathematical relationships implied by the postulates of our theory and related principles, we can derive other expressions which are equivalent to other empirical laws of gaseous behavior. In this way our theory provides an effective model for explaining these laws. The model (the kinetic molecular theory) gives support to the laws. The laws, and the observations on which they are based, give support to the theory. The laws and the theory are mutually supporting. But, as has been noted, the laws do not describe, exactly, the behavior of real gases under any wide range of conditions of temperature and pressure. If our model is to serve to extend our knowledge of the behavior of gases, it must provide a basis for the explanation of the deviations from the empirical laws which we can observe. The theory must help us to understand why real gases do not behave according to the laws, why real gases are not ideal.²

Let us consider the hypothetical situation represented in Figure 4. In a large enclosure, perfectly insulated from the surroundings, we

¹This assumption is known as Avogadro’s hypothesis. It is sometimes included as a postulate in the statement of the kinetic molecular theory. A special quantity of gas, 22.4 liters at zero degrees centigrade (273 Kelvin) temperature and one atmosphere (760 mm of Hg) pressure is called one mole of molecules. On the basis of related theories, observations and calculations of the number of particles in a mole it has been established as \( 6.024 \times 10^{23} \). This is known as Avogadro’s number.

²The word "ideal" as used here has no relation to the concept of perfection. An ideal gas would be a gas which fit the ideas expressed in the model. As far as its usefulness to man is concerned, it might be far from perfect. In fact, if matter were ideal, in this sense, man would not exist.
have two containers linked together with a perfect valve (X). Each chamber has a volume of one liter. In one chamber (A) we have a sample of gas such that the pressure is two atmospheres at a temperature of 300° Kelvin. The second chamber (B) is at the same temperature but contains no gas, the pressure is zero atmospheres. If the valve between the two chambers is opened, the gas will flow from the region of higher pressure (chamber A) to the region of lower pressure (chamber B) until the pressure in both chambers is the same. Since no heat is gained from or lost to the surroundings (the system is perfectly insulated) and no work is done by the gas on the surroundings or by the surroundings on the gas, the process is called an adiabatic free expansion.

In such an hypothetical situation, the gas would expand from a volume of one liter at a pressure of two atmospheres, to a volume of two liters at a pressure of one atmosphere. It can be shown, mathematically, that according to our model (the kinetic molecular theory) there should be no change in temperature. We find that when an experiment is carried out to test this prediction, the temperature always is changed. In most
cases there is a lowering of temperature.  

Here we have an observation which is counter to our theory. What are we to do? If we discard the theory, we must also discard the laws which it supports and restudy all the observations on which those laws are based. This would mean the destruction of an idealional analog which, though limited, we find very useful. Perhaps we can, through a closer look at our theory, find the weakness and modify the theory to take this new observation into account.

This phenomenon (the Joule-Thomson effect), if it is to be explained in terms of our assumption that molecules follow the same laws of motion as have been developed from the study of observable particles, requires that we recognize that some heat energy has been lost in the form of work. Since the expansion is adiabatic, the drop in temperature could not be due to loss of heat to the surroundings. But it was a free expansion; that is, no work was done on the surroundings. Then the loss in energy represented by the drop in temperature must have been expended in doing some sort of internal work on the gas itself. The best explanation which can be given for this is to admit the existence of some attractive forces between molecules. If such attractive forces were to exist, work would be required to pull the molecules apart in expansion. This work would require that the average kinetic energy of the molecules, and therefore the temperature, would be lowered. If we modify postulate three of our theory to take this into account, we can explain the Joule-Thomson effect.

It can also be seen that if gases are made up of material molecules, these molecules must occupy some space even if they were not in motion. In our fourth postulate, we have ignored this volume because it is so small when compared to the volume which the molecule effectively occupies by virtue of its motion. To take into account these two weaknesses in our theory, we can define two concepts. Let us define a concept of the pressure effect of the attractive forces between molecules.

\[\text{This phenomena was first noted and studied by two British scientists, Joule and Thomson (later Lord Kelvin). Their experimental technique was slightly different than that described here but the effect was the same as would be obtained if this experiment could be carried out. They found that at temperatures near room temperature and ordinary pressures, all gases tested, with the exception of hydrogen, experienced a cooling on expansion, while hydrogen actually became warmer. No gases have ever been found which behave as the kinetic molecular theory predicts under these conditions. This phenomenon is known as the Joule-Thomson effect. The rate of change of temperature per unit change in pressure is known as the Joule-Thomas coefficient for the gas. The value of this coefficient is, for many purposes, an important property of the particular gas.}\]
This we could evaluate if we could measure the difference between the "ideal" pressure as predicted by our theory, and the "real" pressure as determined by careful measurement. This difference in pressure due to the attractive forces between molecules we will denote by the symbol $P'$. Let us also denote the volume of the molecule itself by the symbol $b$. We can then modify our theoretical equation of state, $PV = nRT$, to take into account these deviations from our theory. The modified equation $(P+P')(V-nb) = nRT$ (known as van der Waal's equation) more nearly describes the behavior of real gases. In this equation the "ideal pressure" is represented by the sum of the measured pressure ($P$) and the pressure effect of the attractive forces ($P'$). The "ideal volume" is represented by the difference of the measured volume and the "absolute" volume of the number ($n$) of molecules present in the sample. In this way we can improve our theory by making this slight modification, and retain it in our system of thought.

This recognition of the weakness of the theory, developed from the study of the behavior of gases, also helps us to explain the existence of liquids and solids. If these attractive forces (called van der Waal's forces) are assumed to be similar in nature to gravitational forces or electrical field forces, they will be greater the closer together the molecules. In a liquid, since the density is greater than that of the corresponding gas, the molecules must be closer together. The attractive forces may then be great enough to hold the molecules to a definite occupied volume in spite of the kinetic forces due to their motion. If these forces are great enough, the motion of the molecule will be restricted to a slight movement about a relatively fixed position, and the sample of matter will have a definite shape; it will be a solid. The complete solution of van der Waal's equation indicates the existence of such condensed phases.

Our kinetic molecular theory was developed originally to explain the behavior of gases. When we have made the necessary modifications, it serves as an ideational analog from which we can explain, not only the observed properties of gases, but many other properties of matter. By extending these kinetic principles to other forms of matter, we can explain such properties as vaporization and condensation, freezing and melting, surface tension in liquids, the dynamic properties of solutions and colloidal systems, etc. But this improved model also has limitations. It is of little use in explaining the electrical properties of matter. It doesn't help much with the explanation of chemical change. It says nothing about radioactivity. Other logical models, other theories, have been developed in similar ways to explain these other aspects of the behavior of matter. Each general proposition serves as an ideational analog to help us to see relationships among our observations in the particular area involved. Each proposition has its limitations which, when recognized, provide the basis for the extension of inquiry.
ARTICLE IX

READING ASSIGNMENTS

As part of the requirement for the course Natural Science 161, you will be required to complete six written reports on readings in science. You may read reports of scientific inquiry from any source; current news, scientific journals, and books on science, fiction or non-fiction. For each of the first three assigned reports, you will be asked to read a report of scientific inquiry (real or imagined) and analyze it according to the description of science as a system of inquiry presented in this course. You may use a single reading for all these reports if it contains enough material from which to prepare the required analyses. It will probably be more interesting to you, more productive, and more impressive (get a better grade) if you use several sources.

For each of these first three reading reports you will be asked to discuss the example of inquiry in terms of several questions. In the written report of the assignment you should present (in reasonable English or Spanish prose) your report of your reading in terms of these questions. Your report should not be a summary of the material you have read. It should be an analysis of the material in terms of the particular questions asked in the assignment.

The final paper for the course is prepared in the last three reading assignments. In preparation for the writing of this paper, the student should take the following steps:

1. Maintenance of reading cards.

Record of all reading related to this course should be kept on file cards. (The writer prefers 5 x 8 cards for this purpose). For each journal article, selection from an anthology, section or chapter of a book, or other unit of printed material, a card should be prepared and filed so that proper reference can be made in written reports.

Each card should contain an index heading, proper bibliographic notation, a brief summary of the article, and appropriate quotations with page number on which they appear in the article. Any form which the student prefers is acceptable, but consistent form should be followed. The following is the form used by the writer.

Defines the basic structure of the method of intelligence which has come to be called the scientific method. Insists that there is an active element in experience through which connection with past experience and anticipated goals makes experience meaningful.

p. 176 - "So much for the general features of a re-

(over)

2. Write all work in an acceptable style.

The student should obtain a style manual or style sheet appropriate to writing in his anticipated field of specialization and follow it in all writing for which it is acceptable. Acceptable style differs in the several areas of inquiry. Any style acceptable in any area of inquiry, if it is consistently followed, is acceptable for writing for this course.

3. Establish a definite direction.

Direct your reading toward an area of inquiry in which you have a genuine interest. If all your reading for this course is directed by your personal interest, you will be able to do much better work in all your writing. The course, and the assignments, are designed around the consideration of the natural sciences. It will be appropriate and generally easier to do your reading in these areas. However, if you prefer to inquire into some other area of knowledge, outside the natural sciences, you may.

**Reading Assignment 1: Observation**

Select from an appropriate source an example of scientific inquiry in which there is clear presentation of observation of some aspect of the environment. Write a full discussion of the report in terms of the following questions:
1. What is the basic phenomenon being observed?
2. What assumptions are made in planning the observation?
3. What instruments are used in the observation? (If special instruments are designed or unusual application of common instruments is reported, describe these).
4. What measurements are made? (If specific measurements are cited, these should be reported. If not, qualitative description of measurement should be given).
5. Were there any significant unplanned observations? (Examples of serendipity).
6. If you were to plan similar observation, how would you go about it differently? (In this section of your report, you may take full advantage of any knowledge or apparatus which the original investigator did not have at his disposal).

Reading Assignment 2: Development of Relationships

Select a report of inquiry and discuss the process by which relationships among observations are developed. In your discussion, deal with the following questions:

1. What is the basic phenomenon being investigated?
2. What assumptions form the basis for the work reported?
3. What general idea or ideas of relationship are set forth?
4. Are these general ideas developed by the process of induction? (If so, what basic data are used as specific instances)?
5. Is there evidence of intuition or revelation? (If so, cite this evidence).
6. What use is made of the deductive process?
7. How are conclusions tested as to their validity?
8. Is there any point at which you would criticize the logic of the argument presented? (If so, how would you propose to improve or counter the argument)?

Reading Assignment 3: Classification

Select an appropriate example of inquiry and discuss the relationships which exist among classes used in the report. In your discussion, deal with the following questions:

1. What are the principle classes and categories involved?
2. How are these categories related? (Identify the universal class, elemental units, sub-classes, and such relationships as mutually exclusive sets of classes, hierarchical series, and incomparable sets. Where appropriate, use the symbolism of Boolean algebra).
3. Is the classification system adequate for this application? (If not, how would you suggest that it be improved)?
4. To what extent can the system be used in larger application? At what point must the system be revised or extended?
5. Is there any point at which you would criticize the system as it is applied in this example? (If so, how would you propose to improve the system or its application?)

Reading Assignment 4: Analysis of a Question

This is the first of three assignments directed toward inquiry into a question of particular interest to the student. (An alternative set of assignments, related to the study of the development of a concept, is presented in assignments 4, 5b, and 6b). This sequence of assignments is designed to lead the student through the activities of the identification and clarification of a question, the development of an acceptable answer through research of the related literature, and proposal of an observational (experimental) test of that answer. A report will be prepared on each of these phases of the activity of inquiry.

This first report will involve the identification, analysis, and clarification of a specific question proposed by the student. The question may be of any type, on any subject. While this course is specifically directed to the study of the natural sciences, the system of inquiry can be applied to some extent in any area of knowledge.

When a preliminary statement of the question has been made, the question should be clarified and delimited by a process of analysis and evaluation. The end result of this process should be a question of specific interest to the investigator for which an acceptable answer will serve as the key to the original question and/or give direction to further investigation.

The fourth reading report should present this analysis and evaluation in the following manner:

Section 1 - Preliminary statement of the question. In this section of the report the student should state the question as originally posed. It is to be hoped that in the process of analysis and evaluation, the question will be clarified so that a more productive form for the question will result. This result should be reflected in the later sections of the report.

Along with the original statement of the question, the student should present in this section, stipulative definition of any and all terms and phrases used in the statement of the question, which may be open to misinterpretation.

Section 2 - Preliminary analysis of the question. In this section of the report, the student should identify and define a set of relatively simple concepts which seem to be involved in the question as posed. This set of concepts should be derived essentially from the students prior
knowledge rather than from extensive research of related literature. Limited use of general reference sources such as dictionaries, textbooks, and encyclopedia may be helpful, but the essential elements of the analysis should be drawn from the students conventional knowledge.

Section 3 - Preliminary evaluation of the elements. In this section of the report, the student should present, briefly, the assumptions he has made and the conventional knowledge he accepts as regards each of the elements identified in the analysis, as these elements are related to the preliminary statement of the question. As with the report of analysis in section two of the report, the material in this section should reflect the students prior knowledge rather than the result of research of the literature.

Section 4 - Identification of a specific limited question for further study. In this section of the report, the student should present a statement of the question he wishes to investigate for the fifth and sixth reading reports. The question may be of either of these types:

(a) A limited question of substance. If, in the process of analysis and evaluation of the original question, the student derives a question of sufficient interest to him that he wishes to investigate it further, and of sufficiently limited scope that he may hope to find a satisfactory answer through a limited search of the available published literature, a concise, specific statement of the question should be made.

(b) A question of the development of a concept. If, in the process of analysis and evaluation, no limited question of sufficient importance to the student is identified, one significant item of conventional knowledge should be selected for study in terms of the historical development of the concept to its present form. If this alternative is selected, this section of the report should present a concise statement of the concept, in its present form of expression, and indicate the students intention to undertake the study of its development.

Those students who select alternative (a) of section four of this assignment will continue with reading assignments 5a and 6a. Those students who select alternative (b) will continue with reading assignments 5b and 6b.

Reading Assignment 5a: Literature Research, a Limited Question of Substance

This assignment is a continuation of the activities initiated in reading assignment four. If, in the previous assignment, the student identified a reasonably limited question of substance for further investigation he should proceed to review the available literature and, from this conventional knowledge, derive an answer to the question which is
acceptable to him. The results of this inquiry should be presented in this report.

The report should contain clearly identified sections on (1) the statement and clarification of the question, (2) the report of research of related literature, and (3) a brief statement of the conclusion drawn.

The report should be written in concise structure, in an acceptable style. Particular attention should be given to careful use of technical terms, proper structure and punctuation, documentation (footnotes and literature citation) in a consistent manner, and a properly organized bibliography of all reading on the subject, including all references cited and other items appropriate to the subject.

General reference sources (dictionary, textbook, and encyclopedia) should not make up the main body of related literature used. Recent journal articles, monographs, and popular and technical books on subjects related to the question should be used. At least five sources other than general references should appear in the bibliography. (Only items which the student has seriously read should appear).

The report should be as brief as is consistent with the presentation of the material. No specific number of pages is required. If the work can be adequately reported in four pages, four pages should be used. If an adequate treatment requires twenty pages, twenty pages should be submitted. Most good reports will be about eight pages in length, exclusive of the bibliography.

Reading Assignment 5b: Literature Research, Outline of the Study of the Development of a Concept

This assignment is a continuation of the activities initiated in reading assignment four. Those students who elected to study the historical development of a concept, should proceed to trace this development through a review of related literature. The historical development, through successive modifications, from the philosophical roots (usually found in Greek philosophy) to the present form, should be traced.

This report should reflect this development in outline form. The report should contain a sequence of successive statements of expression of the concept dealt with. Each entry should indicate the principal contributors to the particular expression of the concept, and the evidence used to support their argument. The outline may be organized chronologically, or in any other logical order. Each entry should be keyed to the source of information as it appears in the bibliography.

The report should be accompanied by a bibliography, in proper form, of all material appropriate to the subject. General references (dictionaries, textbooks, and encyclopedia) should not make up the main
body of the bibliography. At least four sources such as journal articles or books on the history and philosophy of science should be cited.

The outline should be as brief as is consistent with the presentation of the material. Four pages or less should be sufficient for the purposes of this report.

Reading Assignment 6a: Proposal of an Experiment

This assignment is a continuation of the activities initiated in reading assignment four. If, in the previous assignments, the student elected to investigate a question of substance, and has derived an answer acceptable to him, he should continue with this assignment. If the alternative study of the development of a concept has been elected, the student should proceed with assignment six (b).

In reading assignment five (a) the student has presented a question and an answer to that question derived from a search of the literature. In this report he will propose an observational test of his conclusion. In planning this experimental test, the student may propose any system of observation within reason. Questions of availability of needed equipment and apparatus and problems involved in obtaining materials for observation need not restrict the scope of the proposal.

In planning the experiment, the student should consider these questions:

1. What is the basic phenomenon which you wish to observe?
2. What elements of the environment will be involved in this observation?
3. Which of these factors will be allowed to vary? Which will be controlled? Which will be isolated from the experimental environment?
4. For those factors which are to be isolated, how will this isolation be assured?
5. For those factors which are to be controlled, how will an invariant condition be assured?
6. For those factors which are to be allowed to vary, how will the variation be carried out and the extent of variation measured?
7. What data will be collected?
8. How will these data be interpreted?
9. What evidence will be accepted as confirmation of the accepted answer? What evidence would constitute lack of confirmation?

In the report of this assignment the student should present his proposal for the experimental testing of his answer in terms of these questions. Additional research of the literature may be required. If the proposal is based on or taken from material found in the literature,
the sources should be properly cited. If sources other than those listed in the bibliography of reading assignment five (a) are used, a supplemental bibliography should be included with this report.

Reading Assignment 6b: The Study of the Development of a Concept

This assignment is a continuation of the activities initiated in reading assignment four. Those students who elected to study the historical development of a concept should proceed to write a concise report of the results of their investigation.

The report should present, in reasonable English or Spanish prose, the sequence of thought which has lead to the present expression of the concept. Successive expressions or models should be related by citation of the evidence which has lead to the modification of the concept and showing how this new model better fits this evidence.

The report should be written in concise structure, in an acceptable style. Particular attention should be given to careful use of technical terms and quantitative statements. The written report should contain proper sentence structure and punctuation, documentation (footnotes and literature citation) in a consistent manner. If any related materials were not listed in the bibliography of assignment five (b), a supplemental bibliography should be submitted with this report. (Only sources which the student has seriously read should appear).

The report should be as brief as is consistent with the material presented. No specific number of pages is required. If the work can be adequately reported in four pages, four pages should be used. If an adequate treatment required thirty pages, thirty pages should be submitted. Most good reports will require about twelve pages, exclusive of the bibliography.
LABORATORY EXERCISES

One period each week of the course is devoted to laboratory activities. The purpose of these activities is to give the student first hand experience in activities related to scientific inquiry. In order that optimum value may be derived from these activities, it is necessary that the student participate fully in the exercises. Each exercise is designed to lead the student to experience, in a limited way, the exhilaration and frustration of inquiry. For this reason the directions are not of the "cook-book" type. If the directions are followed and there is participation in the discussion which follows the activities, the purpose of the exercise may be achieved.

One of the basic requirements of scientific inquiry is adequate record keeping. In most organized research, it is required that duplicate record of all activity be maintained. For this purpose, each student is asked to provide for his use a spiral bound notebook of at least eighty sheets and a sheet of carbon paper. Number the sheets (facing sides only) in consecutive pairs of numbers (1, 1, 2, 2, 3, 3, etc.). All record of activities and notes of the discussion are to be kept in the notebook in duplicate. Use only the facing side of each sheet (the reverse side may be used for calculation, scribbling etc.) with the carbon between sheets of the same number so that a continuous duplicate record is maintained. One copy (the duplicate) is to be turned in at the end of each laboratory period for evaluation and criticism. If you have not finished the exercise, turn in the completed sheets, complete the work prior to the next laboratory period and turn the duplicate in to the instructor at the beginning of the next period. If you wish to do any supplemental work related to the exercise, this should also be recorded in your notebook and the duplicate handed in for evaluation and criticism.

Laboratory Exercise 1: Observation and Description

Observation is an activity in which we all have participated since early life. Most people think of themselves as reasonably good observers. Yet there is much more to observation than is generally assumed. It takes concentration, alertness to detail, ingenuity, and often plain patience. It also takes practice.

In this exercise the student will observe a familiar object, a candle, and record as complete a description as he can in the time allowed. The student will observe a candle for a period of about one-half hour. Examine the candle carefully. Light it. Record in your
notebook as many observations as you can in the time allowed. After this period of observation, selected students will read their reports and these will be discussed so as to bring out some of the problems of observation.

During the discussion, record in your notebook the essential points brought out. After the discussion, a short period will be devoted to the development of proposals for further observation of the candle.

At the end of the period, turn in the duplicate of your laboratory notes to the instructor for evaluation and criticism. If you wish to do supplemental work related to this exercise, it is suggested that you proceed to implement the proposed extension of the observation of the candle, or study closely some other common object such as a building, a table, or a piece of jewelry and record your observations in duplicate in your laboratory notebook. After any such period of observation you should propose a plan for further, more detailed, observation of the object.

If you choose to do supplemental work, be sure to keep a duplicate record in your laboratory notebook so that the duplicate may be criticized and credited to your laboratory activities. The original should be retained in your laboratory notebook for future reference.

**Laboratory Exercise 2: Measurement**

This exercise is designed to introduce some problems of measurement. Prior to the beginning of class, each student will be asked to measure some specific characteristic of the environment, such as the distance from one line to another. Each student will record his measurement on the data sheet provided.

From the data presented, these statistics will be calculated:

1. Measures of central tendency; the mean, the median, and the mode.
2. Measures of variation; the range, the mean deviation, and the square-root-mean-square deviation.
3. The percentage variation represented by the mean deviation and the square-root-mean-square deviation.

During this class activity, each student should record in his notebook (in duplicate) notes on the discussion, the data recorded, and the calculations involved in the derivation of the statistics calculated.

After this activity, the students at each table will measure one dimension of the table by at least twelve independent measurements. (Each student will measure the length at least three times). From these data, determine the mean, the median, and the mode of these measurements; calculate the mean deviation and the percent deviation; and record the
measurement, indicating uncertainty, in the notebooks. If the student desires to do supplemental work related to this activity, it is suggested that he take at least twelve independent measurements of some reasonably constant characteristic of the environment and calculate the indicated statistics from the data obtained. (Be sure that you record your observations and calculations in your laboratory notebook and submit the duplicate for criticism and credit).

Laboratory Exercise 3: Observation in the Field

In this exercise we will be taken in groups of about eight persons on a tour of the campus in the vicinity of the classroom (approximately 30 minutes). The guides will point out to you certain plants along the route, give botanical and economic information about them, and answer such questions from the group as he is able. After your return to the classroom, each student will write a concise report of the tour. (About 20 minutes will be devoted to this). From the individual reports, a group report will be prepared.

Reports of these tours will be presented in class and discussion in terms of the ways in which observation and record keeping could be improved.

Maintain in your laboratory notebook the record of your observations made during the tour, your individual report, and your notes of the discussion. Turn in the duplicate from your notebook to the instructor at the end of the period. If you wish to do additional work related to this exercise, it is suggested that you record your observations during some activity of about 30 minutes duration. (A trip, a bull session, watching a dinner group, etc.). If two persons observe the same activities and then compare their records it may add interest.

Laboratory Exercise 4: An Exercise in Deductive Explanation

In this exercise we will attempt to explain several observations by deduction from a series of specific general statements. Your instructor will demonstrate several phenomena. After each demonstration, write out your observations of the phenomenon and your explanation of your observation. Your explanation should be supported by argument based as completely as possible on the following general statements about things.

General Statements About Things: For the purpose of this exercise the following statements about things are assumed to apply to the materials observed.

1. All things are made up of some material we will call stuff, and some quality we will call movement.
2. Stuff tends to stick together, the more stuff in a thing, the more it tends to stick together.
3. Movement tends to separate stuff, the more movement there is, the greater will be the tendency for the stuff to separate into smaller things.
4. Movement may be transferred from one thing (one body of stuff) to another if and only if the two things are in contact with each other.

After each demonstration, a short period will be used to write the explanations. Selected students will report on their explanations and these will be discussed in terms of the following questions.

- Are other assumptions involved in the explanation?
- Is the explanation internally consistent?
- Are conclusions implied by the explanation realistic in terms of general experience or other observations? If not, does the weakness come from the logic of the argument or from the assumptions?

During this exercise the student should record in his notebook his observations, his explanations, and his notes on the discussion of each demonstration.

Laboratory Exercise 5: The Development of Concepts

In this exercise, the class will work in six groups. The students at each table will be provided with two relatively heavy objects, string, and a stand. The instructor will demonstrate the assembly of the materials to produce a pendulum. Working together, the students in each group will then proceed to observe as fully as possible, in the time allowed (about 45 minutes) the action of the pendulum.

Each individual should make a record in his laboratory notebook of all observations. After the period of observation, one student from each group will present a report on the observations made by his group. These reports will be discussed in terms of the ideas set forth in each report. Concepts used in the reports will be identified and defined. Conventional terminology for the expression of these concepts will be agreed upon.

Laboratory Exercise 6: Communication of Concepts

This exercise is designed to give the student experience in following written directions and to illustrate some of the problems which arise from the communication of ideas. At each table there is an operational system in which certain action on the part of the operator will, if properly carried out, bring about certain results. Each system is accompanied by a description of the system, directions for its operation, and an explanation of the effect illustrated.

The exercise will require two consecutive laboratory periods and will be divided into three relatively distinct phases. Each student should maintain in his notebook a continuous record of the activities throughout the sequence.
Phase I: The students at each table will read the description, directions, and explanation for the system. The group should discuss the directions and clarify any questions for each individual in the group. If there are any questions which the group cannot settle, the instructor should be consulted. When the members of the group are sufficiently sure that they understand the directions, they should proceed to carry out the operation and observe the results.

The explanation should then be discussed by the group so that each person understands how the action may produce the observed result. Again, the group should discuss the explanation and clarify any questions for the individual members. If there are any questions that cannot be settled by the group, the instructor should be consulted.

Approximately 30 minutes will be devoted to the activities of Phase I. Each student should record, in his notebook, notes of these activities.

Phase II: After each group has completed Phase I of this exercise, the copies of the explanation of each system will be removed from the table. Half the group will then move on to study the system at the next table. The other members of the group will remain at the original table to explain the system to the students moving to that system. When the new group has become acquainted with the system at that table (about 15 minutes will be devoted to this), the students who remained at the original table will move on to the next table (rejoining the members of their original group) for an explanation of that system.

The process will be continued in similar manner until each group has become acquainted with each of the six systems in the laboratory. (This will require two full laboratory periods).

Each student should record in his notebook, notes on each of the six systems.

Phase III: After each group has become acquainted with each of the systems on display, half of the group will return to their starting point and the system will be explained to them. Since these students are already acquainted with this system, they should note, particularly, any differences in explanation which occur. Comparison of the explanation given by the students at that table with the notes taken in Phase I should be made.

Laboratory Exercise 7: Development of a Logical Model

Many of the concepts of science are descriptions of unobservable entities. The atom, the electron, and the gene are examples. Such entities might be called logical models. They are ideas built up from observation such that their existence can, by logical argument, explain the observations. In this exercise the student will study a system enclosed in a box and attempt to build a logical model to describe what
is inside.

By making small controlled movements of the box and observing the results, it should be possible to gain some insight into the character of the system in the box. The goal of the activity is to describe a system which could account for the occurrences which are observed. DO NOT TRY TO GUESS WHAT THE OBJECTS IN THE BOX ARE.

In each box there are one or more solid objects arranged so that their movement in the box is restricted in some way. Record your observations as they are made. When you have made sufficient observations on which to base a tentative conclusion as to some characteristic of the system in the box, record (in a separate column) this conclusion. Then test this conclusion by using it to predict the response to some new movement of the box. Apply this test and record your observations of the results. Continue in this manner until you can sketch verbally or graphically, the system in the box.

If you wish to do supplemental work for this exercise, you may come to the laboratory during the day and continue with the study of your assigned box or with another box.

Laboratory Exercise 8: Logical models -- Criticism

This exercise is an extension of the activities of exercise seven. In the previous exercise, each individual developed a model of a system in a closed box. In this exercise each student will be given one of the boxes and the report of observation of another student. The object of this exercise is to criticize and extend the model developed by the other student.

Begin by repeating the observations reported, to see if you agree with the interpretation given. Record the action taken, the other student's observation, and any modification you would make in the report. It may not be necessary for you to repeat all of the reported observations. When you have established general agreement with the other's observations or significant new observation, you should proceed to add to the report.

Continue the process until you have made some significant contribution to the model developed by the other student. Sketch your improved model of the system in the box.

If you wish to do supplemental work related to this exercise, it might be interesting to criticize your own model developed in the exercise seven.

Laboratory Exercise 9: Classification

This exercise is designed to give the student experience in the evaluation and application of a conventional system of classification.
The system used is a simplified system for the classification of leaves. At the beginning of the period, the class will discuss the system as presented in terms of the following questions.

Are the descriptive definitions adequate? Are the figures understandable?
What relationships exist between classes as defined? Are several classes mutually exclusive? Are there any hierarchical series involved?
Are any classes in the system empty by definition?
What is the total number of classes defined in the system?

When the system has been adequately defined, through this discussion, the class will tour the campus in the vicinity of the classroom and observe leaves of several plants. In the course of the tour, the various leaves will be classified and the system judged in terms of these questions.

Is the system complete so far as the leaves observed are concerned? Is there a class in which every element is a member? If not, what improvement in the system is required?
Is the system organized for optimum utility? Would some other organization of characteristics be more effective?
Is classification of leaves according to this system sufficient for defining the plant from which the leaf comes?
Are there any serious practical problems of application of the system which detract from its value?

The student should note in his laboratory notebook, any significant points developed in the preliminary discussion, in the discussion during the tour, and any questions which he has about classification in general or about this particular system.

If supplemental work related to this exercise is desired, it is suggested that the student take another simple system of classification and analyze it in terms of the questions posed in this exercise.

Laboratory Exercise 10: The Development of an Empirical Law

In this exercise we will again work in six groups with the pendulum. In exercise five we identified several concepts involved in the description of the motion of the pendulum. In this exercise the student will observe the relationships among these variables. In order to study these relationships effectively, plan the observation so that as many of the variables are controlled as possible and only two factors are allowed to vary significantly in any one series of observations.

For each set of observations, record the measure of the variables as one of the factors is varied. The data from the several groups will be recorded on the board so that comparisons may be made. In those cases in which there seem to be a consistent relationship, the data will be treated according to certain mathematical models of relationship so as
to develop a simple general statement of the relationship (an empirical law).

Laboratory Exercise II: Reports of Inquiry

The remaining laboratory periods will be devoted to the oral reports of individual inquiry carried out in conjunction with reading assignments four, five and six. Each student desiring to report on his inquiry will be allowed twenty to thirty minutes to present to the class the results of his inquiry.

A portion of each period will be devoted to questions from the class. The students in the class should take notes on the reports and participate in the criticism of each report.
APPENDIX D

DESCRIPTION OF ACTIVITIES FROM

ONE LABORATORY EXERCISE
Laboratory Exercise 4: An Exercise in Deductive Explanation

In this exercise we will attempt to explain several observations by deduction from a series of specific general statements. Your instructor will demonstrate several phenomena. After each demonstration, write out your observations of the phenomenon and your explanation of your observation. Your explanation should be supported by argument based as completely as possible on the following general statements about things.

General Statements About Things -- For the purposes of this exercise the following statements about things are assumed to apply to the materials observed.

1. All things are made up of some material we will call stuff, and some quality we will call movement.
2. Stuff tends to stick together, the more stuff in a thing, the more it tends to stick together.
3. Movement tends to separate stuff, the more movement there is, the greater will be the tendency for the stuff to separate into smaller things.
4. Movement may be transferred from one thing (one body of stuff) to another if and only if the two things are in contact with each other.

After each demonstration, a short period will be used to write the explanations. Selected students will report on their explanations and these will be discussed in terms of the following questions.

Are other assumptions involved in the explanation?
Is the explanation internally consistent?
Are conclusions implied by the explanation realistic in terms of general experience or other observations? If not, does the weakness come from the logic of the argument or from the assumptions?

During this exercise the student should record in his notebook his observations, his explanation, and his notes on the discussion of each demonstration.

At the beginning of the laboratory period the instructor writes on the chalk board the four postulates of the General Statement About Things and the criteria to be used in the discussion.

The instructor has, on the demonstration stand, the following materials: (1) two one liter beakers, one about half full of water, the other containing about the same quantity of ice; (2) a bunsen burner with gas source (or other source of flame for heat); (3) a set of "ball and ring" apparatus for demonstration of volumetric expansion, a set in which the ring is heated to allow the ball to pass through is preferred;
and (4) a bimetallic strip for demonstration of differential expansion of metals.

Preparatory to this exercise, in lecture on the use of conceptual systems, the General Statement About Things was used to illustrate the development of a conceptual system of thought. The concepts of heat, as a property related to movement of stuff, and temperature, as a measure of the direction of heat flow, were developed. The nature of flame as a source of heat, and thus movement, was established.

The activity proceeds in a manner such as this:

Instructor: Today we are going to observe three relatively simple phenomena. You are asked to record your observation, develop an explanation of each one, and take notes on the discussion involved. I will demonstrate the first phenomenon. As I do, record in your notebook your observation. You will then spend a few minutes writing out your explanation. We will discuss these explanations in terms of these questions (indicates the questions on the chalk board). You should record in your notebook your observation, your explanation, and your notes on the discussion.

Remember your explanation should be made in terms of the postulates as far as possible. Are there any questions before we begin?

The instructor indicates the two beakers and feels the "stuff" in each.

Instructor: I have here two samples of stuff. One is liquid (splashes the water). The other is solid (holds up a piece of ice). I got this solid stuff by putting some of this liquid stuff in a thing called a refrigerator and leaving it there for some time.

Both kinds of stuff feel wet. They both smell the same, not at all. Neither one has any distinguishable taste. When I hold the solid stuff in my hand for a while, some of it goes away and stuff like the liquid drips off my hand. The solid stuff feels much colder than the liquid stuff.

Can you explain how these two kinds of stuff can have this appearance?

Take about ten minutes to write out your explanations. If you have any questions, I will try to answer them, if I can. If you need to observe more closely, you may come up to the table and feel the stuff for yourself.

When observable water has collected in the beaker containing the ice, it is called to the attention of the class and the ice is poured into the beaker containing the water.

During the writing period the instructor circulates through the room and, reading over shoulders, picks out students whose explanations exemplify ideas which he wants to bring out in the discussion.
Instructor: Does someone have an explanation? (It is usually necessary to call on some particular student in order to get a response).

Student A: The ice and water are the same thing. The difference is the ice is colder. When it is colder, it freezes. When it gets hot it melts and becomes liquid. The refrigerator made it cold. Your hand makes it warm and melt. The ice melts in your hand and becomes water. When the molecules of water get warm, they get bigger and separate so it melts. When they get cold they shrink and pack together tighter so it freezes, that's all there is to it.

Instructor: Is this an adequate explanation? I guess if it seems adequate to you it is adequate, but is it adequate in terms of our questions? Are assumptions other than our General Statement About Things involved?

You said when it is cold it freezes, when it is warm it melts. Is this an explanation?

You just say what I said more simply in other words. We might call this a semantic reorganization of our observation, but it does not constitute an explanation. We often find that what is supposed to be an explanation is really just a different way of saying the same things, a semantic rearrangement of ideas.

When you do start explaining, you use the word "molecule." What is a molecule? What does a molecule look like? You assume that stuff is made up of molecules. Is this part of our system, one of our postulates?

You have ignored our postulates and made up a new system of your own. That is all right. Maybe your system is better than ours. But that's not what we were supposed to do in this exercise.

Can someone give us an explanation in terms of our system?

If the instructor has noted a student's explanation which uses the postulates, he should call on that student. If not he gives his own explanation.

Instructor: How is this? When I hold the ice in my hand, movement is transferred from my hand to the ice (according to postulate 4). This would happen if my hand were at a higher temperature than the ice. A thermometer would indicate this to be the case.

As the stuff in the ice gets more movement, it tends to separate more (according to postulate 3). As it separates it reaches a point at which it can move about as a liquid.

Is this an adequate explanation?
Are other assumptions involved?

Student X: You assumed that your hand was hotter than the ice.

Instructor: That might be regarded as an assumption. Can we check this assumption in some way?
Is the explanation internally consistent?
Well, unless you can show me the logical weakness, I say it is.
Are conclusions implied by the explanation realistic in terms of other observations?

We said the movement from the hand makes the stuff separate. Then the liquid should be less dense than the solid. (Indicate the beaker containing the ice in water). Is it?

Then there is something wrong with the explanation. We agreed that it was internally consistent. Something must be wrong with our General Statement.

It happens that for most kinds of stuff (stuff which I have observed and read about) the liquid is less dense than the solid. Let's just say that water is peculiar stuff. Then we can keep our General Statement About Things for a while longer.

The other two demonstrations are handled in similar manner. In the "ball and ring" demonstration the explanation, "Heat causes the ring to expand," is accepted when thermal expansion is explained in a manner similar to that for the "water-ice" demonstration.

The meaning of "internal consistency" is illustrated by challenging the explanation on the basis that expansion of the ring will cause the space around the ring, and thus the hole, to get smaller.

Someone will usually call up postulate 3 as the basis for an assumption of some preferential outward expansion to explain the larger hole.

This is used to illustrate the frequent need for some additional assumption.

Clarification through consideration of linear expansion of the circumference of the ring is then presented. This serves also as an illustration of the value of mathematics as a source of ideational models.

In the demonstration of the bimetallic strip, the students are told that brass is more dense than iron. Since the strip curves with the brass on the outer side of the curve, the system seems to contain a paradox; even though the brass contains more stuff it separates more and expands more. This is contrary to postulate 2. It is shown that this paradox involves the assumption that the brass and the iron take up equal movement. If it is assumed that the brass takes up more movement than the iron, the explanation seems valid. This assumption can serve as the basis for the development of the concept of specific heat. The specific heat of brass and iron can be measured.

The students are told that when this measurement is made it is found that the specific heat of brass is greater than that of iron, and thus the explanation is supported. The measurement of specific heat could thus be developed as a productive next laboratory activity.
APPENDIX E

SAMPLE EXAMINATION
Natural Science 40-161       Final Examination       Spring 1965

PLEASE FILL IN THE INFORMATION AT THE TOP OF THE ANSWER SHEET COMPLETELY

The answer sheet contains space for answers to 60 multiple choice items. For each item in the test booklet, mark not more than one response on the answer sheet. Indicate your answer for each item by blocking out completely the number corresponding to your choice of the answers given for that item. If you wish to change your answer, mark through your original answer with a large X. Then block out the number corresponding to your new answer.

1. For our definition of science, we assumed that man's environment is understandable. It follows from this assumption that:
   1. the world around us is controlled by errant spirits, free to act on whim and caprice.
   2. scientific knowledge is knowledge of the truth about the environment as it exists in nature.
   3. the universe in which man exists operates according to some unifying principles.
   4. modern man is scientific since he understands his environment.
   5. only a scientist can properly interpret the behavior of the environment.

2. It is sometimes said that the thing which distinguishes man from other animals is his desire to understand and his ability to develop explanations. If this is accepted as the fundamental human characteristic responsible for man's development of science, we may say that:
   1. the essence of humanity is understanding.
   2. the control and use of his environment is what makes man "man."
   3. man used fire for thousands of years before he tried to understand it.
   4. the development of theory always precedes related utilization of things.
   5. the most important invention of the scientific mind is the wheel.

3. Most scientists today accept the molecular hypothesis because:
   1. with modern instruments such as the electron microscope, we can observe molecules directly.
   2. all matter is made up of molecules; if there were no molecules there would be no matter.
   3. if molecules behaved as the Kinetic Molecular Theory predicts, there would be no solids or liquids.
   4. the properties which we observe for the molecule are also observed in microscopic particles.
   5. if molecules exist and have the properties which are assigned to them, we can more effectively explain our observation of matter.
4. By "the fallacy of identification" we mean:
   1. the assumption that verbal expression reflects reality.
   2. the assumption that man is capable of observing reality completely.
   3. the assumption that verbal expression reflects man's interpretation of his observation.
   4. the assumption that reality exists independent of man's observation.
   5. the assumption that man is capable of understanding.

5. Which of the following best defines the concept of "inquiry" as this term is used in this course?
   1. inquiry is a natural process by which man develops his mental faculties.
   2. inquiry is an abstract description of the way in which man comes to know the truth.
   3. inquiry is meaningless since what man knows he knows as a result of the use of higher mental processes.
   4. inquiry is a set of defined operations to be taken in specific order so as to derive knowledge.
   5. inquiry is an ongoing process of the human mind through which man derives and organizes functional knowledge.

6. Before we can hope to develop understanding and use of the things in our environment, we must observe the behavior of the world around us, because:
   1. reality exists only in the human mind.
   2. the physical scientists have told us how the elements of the environment affect us.
   3. we can only believe what we observe directly.
   4. the nerve energy which furnishes the motive power for thought is continuously derived through observation.
   5. before we can hope to understand anything, we must be aware of it.

7. Concentration is:
   1. necessary for complete observation.
   2. directed and guided by purpose and interest.
   3. impossible in modern society.
   4. all of these (1, 2, and 3).
   5. none of these (neither 1, 2, nor 3).

8. We must insist on careful record keeping as an essential part of scientific observation because:
   1. we must provide some way for later extension and review.
   2. scientists have always been known as careful record keepers.
   3. before we can observe scientifically, we must know what others have observed before us.
   4. if we hope to gain credit for our contribution to science, we must have evidence of our observation.
   5. it is a well known principle of psychology that we tend to see what we wish to see.
9. It has been said that all learning begins with a problem. Which of the following statements is an acceptable judgment of this statement?
1. the statement is absolutely true.
2. the "truth" of the statement depends on the definition of the concepts reflected by the words "learning" and "problem."
3. since we can learn in our sleep, the statement is not always true.
4. since the best scientific method is the formal method, which requires no problem, the statement has no relation to scientific inquiry.
5. since scientific inquiry has no relation to learning, the statement is of no interest to scientists.

10. Which of the following is NOT a postulate of the Kinetic Molecular Theory?
1. all matter is made up of molecules.
2. molecules are composed of atoms in chemical combination.
3. molecules are in constant, rapid, random motion with average energy dependent on the temperature.
4. collisions between molecules are perfectly elastic.
5. the volume of the molecule is negligible with respect to the volume it effectively occupies.

11. Which of the following is NOT NECESSARILY a characteristic of an effective classification system?
1. there is a defined superclass in which all concepts being classified are elements.
2. there is a set of subclasses such that every element in any subclass is a member of the defined superclass.
3. the subclasses are mutually exclusive and totally exhaustive in the defined superclass.
4. elements are included in or excluded from any one subclass on the basis of similarities or differences with respect to other elements.
5. the definitions of all classes and elements are understandable to the persons using the system.

12. It is said that there are three criteria for judging a proposition; the logical, the semantic, and the pragmatic. For such judgment to be absolute would require that we have:
1. a perfect system of logic.
2. a perfect language.
3. complete knowledge of the future.
4. all of these (1, 2, and 3).
5. the first and second but not necessarily the third (1 and 2 but not 3).

13. It is said that to be absolutely complete in our observation, we must observe with all our senses in the most minute detail, but to do so would require such time and concentration that we would never have done with it. From this statement we may conclude that:
1. effective observation is impossible.
2. empirical knowledge is always incomplete, therefore inferior to knowledge gained through higher thought processes.
3. from our observation of a small part of an animal, we may properly define the character of the whole animal.
4. we must settle for something less than perfection and hope for improvement through continuous extension and review.
5. it is necessary, if we are to have an organized body of knowledge, that we defer explanation until we have complete observation.

14. The metric system of measurement is preferred in scientific work because:
1. all basic units are naturally defined, therefore it is the best system for the study of nature.
2. all conversion factors are powers of ten, therefore arithmetic is easier in the decimal system of numerals.
3. it is only the English and their economic and political associates who use any other system.
4. the system is used only for scientific work, therefore it can be protected against misuse and misunderstanding.
5. in science, we have no need for measurements made by persons who are not scientists.

15. It is said that all physical measurement may be expressed as some combination of measure of four quantitative characteristics. Which of the following is NOT one of these fundamental dimensional factors of physical measurement?
1. volume; 2. mass; 3. length; 4. time; 5. number.

16. An advantage of laboratory observation is:
1. careful control of conditions of observation makes duplication more readily possible.
2. the elements of the environment under observation behave more naturally in the laboratory.
3. complete isolation and control of unwanted variables is always possible in the laboratory.
4. all of these (1, 2, and 3).
5. none of these (neither 1, 2, nor 3).

17. By the "Idols of the Mind," Bacon means:
1. principles we use to explain the things we understand.
2. conceptual schemes which we develop for communication of our ideas.
3. physical analogs which we use in the development of relationships.
4. habits of thought and expression which restrict the effectiveness of inquiry.
5. stories invented for the stage, more compact and elegant than stories out of history.
18. An empirical law is:
   1. any mathematical statement of relationship, such as an algebraic formula.
   2. a relatively simple verbal or symbolic statement which effectively summarizes a series of observations.
   3. a statement of relationship which all things in nature must follow.
   4. a statement of relationship which man must recognize if he hopes for understanding.
   5. a statement about the behavior of nature which man may ignore or transgress only at great risk.

19. It is sometimes held that the ultimate criterion of value is usefulness. The weakness of this position lies in:
   1. the need for an historical view of the results of application.
   2. the absence of a "theory of progress" from which to predict future usefulness.
   3. the need for clear definition of present position and desired direction.
   4. all of these (1, 2, and 3).
   5. none of these (neither 1, 2, nor 3).

20. Which of the following is NOT explicitly set forth as one of the steps in the "formal" model of problem solving?
   1. comprehension of the problem.
   2. analysis into its elements.
   3. evaluation of the identified variables.
   4. formulation of an hypothesis.
   5. solution of the problem.

21. The deductive process is particularly useful in the development of:
   1. explanation of observed phenomena.
   2. prediction of new observation.
   3. support of argument for previously drawn conclusion.
   4. all of these (1, 2, and 3).
   5. none of these (neither 1, 2, nor 3).

22. The general statements derived by induction are uncertain because:
   1. they are always based on observation which is uncertain.
   2. truth can only be obtained through the use of higher thought processes.
   3. a general statement is valid only if based on a large number of specific observations.
   4. the inductive process is not subject to the fundamental rules of logic, therefore it cannot be logical.
   5. not all girls are pretty.

23. In the cycle of induction-deduction-experimentation:
   1. our generalizations are derived by deduction and proved by experimentation.
   2. our generalizations are derived by induction and tested by deduction.
3. our generalizations are derived by induction and tested by experimentation.
4. our generalizations are derived by deduction and new predictions made through experimentation.
5. our generalizations are derived by deduction, predictions made by experimentation, and tested by induction.

24. Analogy is effective as a basis for seeing new relationships in a system only when:
1. the two systems are exactly identical.
2. the limitations of the analogy are recognized.
3. a physical model of the system is constructed.
4. its use is limited to relationships known to exist in both the system and its analog.
5. the analog is derived from a purely deductive system such as one of the mathematical systems.

25. The formal model of problem solving is particularly useful in:
1. dealing with problems involving mathematical derivations and interpretations.
2. ordering present knowledge so as to identify areas of ignorance.
3. organizing, post factum, the report of the results of inquiry.
4. all of these (1, 2, and 3).
5. none of these (neither 1, 2, nor 3).

26. An example of an hierarchical series is:
1. plants, animals, minerals, water, air.
2. dogs, cats, rodents, mammals, animals.
3. dogs, cats, rabbits, horses, mammals.
4. dogs, cats, rabbits, horses, cows.
5. dogs, mammals, vertebrates, animals, living things.

27. The "doctrine of sufficient reason" leaves unanswered which of the following questions?
1. what questions are of value for inquiry?
2. what phenomena are worthy of investigation?
3. what properties of the environment are to be observed?
4. all of these (1, 2, and 3).
5. none of these (neither 1, 2, nor 3).

28. We reject the assumption that matter is continuous because:
1. such an assumption provides no basis for explanation of diffusion in gases.
2. if matter were continuous, we could subdivide a sample infinitely without losing its identity.
3. we know matter is made up of molecules.
4. all of these (1, 2, and 3).
5. none of these (neither 1, 2, nor 3).
29. One definition of a concept is a cluster of ideas which may be expressed by a relatively simple verbal or symbolic expression. From this definition we may conclude that:
1. a concept is the private property of an individual.
2. the expression of a concept must reflect all of its elemental ideas.
3. for consistency's sake, a concept, once formed, may never change.
4. all of these (1, 2, and 3).
5. none of these (neither 1, 2, nor 3).

30. Complete definition is impossible because:
1. man is incapable of understanding the complete truth of anything.
2. definition must be made in words which can never adequately express ideas.
3. truth changes with time, thus definitions must change.
4. our words derive meaning from the way in which they are used, thus cannot be defined out of context.
5. definition must be made in words or symbols which must then be defined.

31. In science we prefer stipulative definition because:
1. categories and classes are realities of nature, thus form a natural basis for definition.
2. a stipulative definition must be categorical, descriptive, or some combination of these two.
3. stipulative definition makes use of analogy which is our most certain form of reasoning.
4. stipulative definition is brief and concise, in keeping with the preferred literary style of science.
5. to clearly define a term we must use it in as many different ways as we can until its meaning is clear to the other person.

32. Which of the following is NOT explicitly required in the model of problem solving attributed to John Dewey?
1. some present knowledge from which a problem can arise.
2. a goal toward which we are striving.
3. a barrier which prevents our reaching our goal.
4. the proposal of a possible way to surmount the barrier.
5. active testing of the proposed solution to the problem.

33. A measure of 1763 centimeters is equivalent to a measure of:
1. 1.763 meters; 2. 17.63 meters; 3. 176.3 meters; 4. 17630 meters; 5. 176300 meters.

34. Which of the following numbers is written with five significant digits?
1. 20070; 2. 20.070; 3. 0.00270; 4. 27000; 5. 0.0027.

35. Which of the following is the properly denoted exponential expression for the number 49600?
Which of the following is an expression of the commutative law of addition for the natural numbers?

1. \( x = y \) and \( y = z \) \( \rightarrow \) \( x = z \)
2. \( x + y = z \) \( \rightarrow \) \( x + z = y \)
3. \( x = y \) \( \rightarrow \) \( x + z = y + z \)
4. \( x + y = z \) \( \rightarrow \) \( y + x = z \)
5. \( x = y \) \( \rightarrow \) \( x^3 = y^3 \)

Items 37 through 42 refer to a classification system represented by this Venn diagram:

In items 37 through 41, select the Boolean expression which represents the indicated regions (numbered areas) of the diagram.

37. Regions 3, 4, and 5 only.
   1. \( A \cap B \cap C \)
   2. \( A \cap B \cap C \)
   3. \( A \cup B \cup C \)
   4. \( A \cup B \cup C \)
   5. None of these.

38. Regions 2, 3, 4, 5, and 6 only.
   1. \( A \cap B \cap C \)
   2. \( A \cup B \)
   3. \( B \cup C \)
   4. \( A \cap C \)
   5. None of these.
39. Regions 1, 2, 6, 7, and 8 only.  40. Regions 4, 7, and 8 only.
1. \((A \cap B \cup C)'
2. \((A \cup B \cup C)'
3. \((A \cup B) \cap C
4. \(A \cup (B \cap C)'
5. None of these.

41. Regions 1, 7, and 8 only.
1. \((A \land B)' \cap 0
2. \((A \lor B)' \cup 0
3. \((A \land B)' \lor I
4. \((A \lor B)' \lor I
5. None of these

42. Which of the following pairs of regions would have the same description?
1. regions 1 and 4.
2. regions 2 and 6.
3. regions 3 and 5.
4. regions 7 and 8.
5. regions 8 and 1.

43. The system of dimensional and unital analysis is referred to as a pseudo-mathematical system because:
1. it does not involve a system of numerical symbols as does any mathematical system.
2. the undefined terms may be defined by use of other terms from the systems of mathematics.
3. it has no value as a source of ideational analogs as do the mathematical systems.
4. one criteria for judgment of the validity of a proposition includes ideas from outside the system.
5. all the criteria for judgment of the validity of a proposition are entirely defined within the system of mathematics.

Items 44 through 50 are based on the following reports of the weight of an object:
14.6 grams; 14.8 grams; 14.4 grams; 14.9 grams; 14.8 grams;
14.4 grams; 14.7 grams; 14.8 grams; 14.9 grams.

44. The mode of these data is most nearly:

45. The median of these data is most nearly:

46. The arithmetic mean of these data is most nearly:
47. The range of these data is most nearly:
   1. 0.9 grams; 2. 0.7 grams; 3. 0.6 grams; 4. 0.24 grams; 5. 0.4 grams.

48. The mean deviation of these data is most nearly:
   1. 1.4 grams; 2. 1.0 grams; 3. 0.4 grams; 4. 0.24 grams; 5. 0.14 grams.

49. The percent deviation of these data is most nearly:
   1. 1.5%; 2. 1.3%; 3. 1.1%; 4. 0.9%; 5. 0.1%.

50. The square root mean square deviation of these data is most nearly:
   1. 0.6 grams; 2. 0.4 grams; 3. 0.2 grams; 4. 0.06 grams; 5. 0.02 grams.

51. It is said that published information is generally more reliable than private opinion because:
   1. published information has been subjected to more thorough criticism.
   2. a good idea is more likely to originate in the thinking of a group than in the thinking of an individual.
   3. private opinion is usually based on some assumptions while published information must be based on fact.
   4. all of these (1, 2, and 3).
   5. none of these (neither 1, 2, nor 3).

52. For an answer to a question to be acceptable in personal inquiry, it must:
   1. be consistent with the conventional knowledge of the area as represented in the published literature.
   2. continue through the sphere of knowledge and penetrate the surface of ignorance which surrounds knowledge.
   3. make some significant contribution to the extension of the knowledge of mankind.
   4. satisfy the purpose and interest of the individual or group involved in inquiry.
   5. ultimately involve only the organization of conventional knowledge.

53. Intelligent inquiry requires that we:
   1. accept any hypothesis which can withstand the fierce light of logic.
   2. reject each hypothesis which fails to meet the test of action and admit that we have made a mistake.
   3. recognize the limits of human intellect and accept something less than the best available.
   4. test every conceivable hypothesis before we accept any one.
   5. use the information gained from testing an unacceptable hypothesis to improve those which follow.
54. Which of the following is NOT characteristic of a useful model?
1. within the limits of the analogy, there is one to one correspondence between the elements of the system and the model.
2. the model represents only in a limited way, the characteristics and relationships in the system under study.
3. for every element which can possibly be identified in the system, there is at least one corresponding element in the model.
4. within the limits of the analogy, corresponding parts in the system and the model have similar relationships.
5. the model may be a physical analog device or an ideational structure.

55. It is often said that many of our most serious problems are due to "cultural lag." If this is accepted, which of the following would be a reasonable approach to the problem posed by this fact?
1. halt all development in the natural sciences until our knowledge in other fields of inquiry catches up.
2. use the methods of the physical sciences in other areas of inquiry.
3. strive to develop methods of inquiry which would increase the rate of growth of understanding in other areas of inquiry.
4. all of these (1, 2, and 3).
5. none of these (neither 1, 2, nor 3).

56. Which of the following is NOT an essential element in a mathematical deductive system?
1. a set of primary, undefined terms.
2. a system of numerical symbolism.
3. a set of assumptions called axioms or postulates.
4. a set of well defined operations.
5. a series of propositions which can be "proven" logically from the definitions, postulates, and previous propositions.

57. A logical model may be said to be:
1. a description of reality as we see it.
2. a directly observable physical reality expressed in language.
3. a verbal or symbolic expression of observed reality which is understandable.
4. an ideational analog which helps us to explain our observation.
5. a verbal description of concrete reality which we can observe directly.

58. Which of the following is NOT a NECESSARY part of research activity?
1. the formulation and definition of a problem.
2. a thorough search of the related literature.
3. the development of some new technique of measurement.
4. the collection and interpretation of data.
5. the preparation of a report of the research.

59. For a new procedure to be reliable it must:
1. give exact quantitative measure of some characteristic of the environment.
2. provide an adequate numerical valuation of the extent of presence or absence of some characteristic.
3. give similar results when applied in similar situations.
4. give a measure of the extent to which the characteristic it is supposed to measure is present or absent.
5. all of these (1, 2, 3, and 4).

60. The continuing acceleration in the rate of increase of conventional knowledge, which we have called "The Knowledge Explosion" has resulted in:
1. a need for ever more narrow specialization of research and inquiry.
2. the development of group research in which each task is assigned to a specialist in that activity.
3. confusion as to what knowledge will be necessary in the near future.
4. all of these (1, 2, and 3).
5. none of these (neither 1, 2, nor 3).

ON THE LOWER HALF AND THE REVERSE SIDE OF THIS ANSWER SHEET, answer the following:

I. Explain the fundamental differences between the natural sciences and the social or behavioral sciences which make the former more respected, as science, than the latter.

II. Throughout the laboratory activities of the course, we have stressed the need for keeping an adequate record of our observation at the time it is carried out. List five factors which make this difficult to do and explain how each may be overcome.

III. List, in proper bibliographic form, five examples of published materials (books or articles) which you have read during this term.

PLEASE PLEASE PLEASE PLEASE PLEASE PLEASE

Write your answers legibly on the answer sheet in clear concise English or Spanish prose so that they may be read with reasonable clarity.
APPENDIX F

CLASSIFICATION OF OBJECTIVES OF THE COURSE
Cognitive Objectives

1.00 Knowledge
   1.10 Knowledge of specific items of information presented in the activities and text.
   1.11 Knowledge of terminology.
   1.12 Knowledge of specific facts.
   1.20 Knowledge of principles presented in the activities and text.
   1.21 Knowledge of the function of the elements of inquiry as analyzed.
   1.22 Knowledge of characteristic activities of inquiry which are identified.

2.00 Comprehension — ability to make use of materials and ideas involved in inquiry as presented.
   2.10 Ability to interpret written material in terms of systematic inquiry.
   2.20 Ability to extend the application of principles of inquiry to areas beyond those presented.
   2.30 Ability to effectively deal with novel problems.

3.00 Application — the use of generalizations about inquiry in particular and concrete situations.

4.00 Analysis — making clear the pattern of ideas present in written material and situations.
   4.10 Effective critical analysis of reports of scientific inquiry.
   4.20 Effective analysis of a description of a situation so an identification of areas open to inquiry may be made.

5.00 Synthesis — structuring of a unitary pattern from elements and specific data.
   5.10 Constructive criticism of reports of scientific inquiry.
   5.20 Production of realistic proposals for programs of inquiry.
   5.30 Derivation of productive relationships among data.

6.00 Evaluation
   6.10 Establishing criteria for judgment.
   6.20 Application of criteria for judgment.
Affective Objectives

1.00 Receiving -- the development of habits of attention.
   1.10 Attendance and awareness during activities.
   1.20 Alertness during activities.
   1.30 Apparent involvement in activities.

2.00 Responding -- the development of interest in the activities of inquiry.
   2.10 Acceptance of required participation in the activities.
   2.20 General willingness to participate in the activities.
   2.30 Active involvement in the activities with apparent satisfaction.

3.00 Valuing -- development of a positive attitude toward inquiry and the processes of research.
   3.10 Acceptance of the value of inquiry as a means of coming to know.
   3.20 Preference for active inquiry as opposed to scholastic attainment of knowledge.
   3.30 Commitment to the processes of inquiry as a means of personal intellectual growth.

4.00 Organization -- development of appreciation of the significance of scientific inquiry in society.
   4.10 Development of a rationale as to the place of science and scientific inquiry in social development.
   4.20 Formulation of judgment of the value of intellectual and material advancement which results from scientific inquiry.

5.00 Characterization -- development of intellectual honesty and openness to criticism.
   5.10 Generalized set -- development of personal orientation which allows freedom of thought.
       5.11 Willingness to accept new evidence and alter opinions when this is called for.
       5.12 Willingness to hear criticism of self and own ideas.
       5.13 Habit of objective approach to problems.
   5.20 Characterization -- development of devotion to intellectual honesty.
       5.21 Engagement in serious personal criticism of own ideas and acts.
       5.22 Action guided by a consistent philosophy of life.
BIOGRAPHICAL SKETCH

Charles Kelland Evans was born August 4, 1922, at Boise, Idaho. In June, 1940, he was graduated from Central High School, Ypsilanti, Michigan. From 1940 until 1945 he served as an enlisted man in the United States Army Infantry, where he achieved the rank of Technical Sergeant. Following his discharge from the Army he attended, in succession, Michigan State University, the University of Michigan, and Southern Illinois University. He received the degree of Bachelor of Science from Southern Illinois University in June, 1950. Mr. Evans continued to study at Southern Illinois University on a part time basis and during summer sessions until 1960. He received the degree of Master of Science in Education from this institution in 1956. From June, 1962, to date he has continued his work toward the degree of Doctor of Education at the University of Florida.

Mr. Evans taught in a small rural elementary school in Williamson County, Illinois, during the 1950-1951 school year. From 1951 until 1957 he taught mathematics and science in secondary schools in Golconda and Murphysboro, Illinois. In 1957 he joined the faculty of the Chemistry Department at Southern Illinois University, where he remained until 1960. In 1960 he was appointed to the position of Head of the Department of Science Education at Inter American University of Puerto Rico. In July, 1965, he assumed the position of Dean of Basic Sciences at Central Florida Junior College.

Charles Kelland Evans is married to the former Lorene Davis of Creal Springs, Illinois, and is the father of two daughters. He is a member of the American Chemical Society and Phi Delta Kappa.

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This dissertation was prepared under the direction of the chairman of the candidate's supervisory committee and has been approved by all members of that committee. It was submitted to the Dean of the College of Education and to the Graduate Council, and was approved as partial fulfillment of the requirements for the degree of Doctor of Education.

August 14, 1965

[Signatures and names]

Dean, College of Education

Dean, Graduate School

Supervisory Committee:

N. E. Bunting
Chairman

[Signatures and names]