Teaching Science by Inquiry in the Secondary School

second edition

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Preface

The preface of our well-received first edition affirmed that science education was in a state of great change. Proof of that assertion is this extensively revised second edition. Our profession is truly a dynamic one necessitating constant self-improvement and modification of materials and methods.

There presently are indications that science education is moving toward a more inclusive view of teaching emphasizing greater concern for the development of the total person. Students involved in investigating science utilize and manifest their observational skills, rational processes, and other human traits. Because there is evidence that inquiry-oriented teaching helps students to make self-discoveries about their various talents, we have continued to devote considerable attention to methods fostering this approach. More emphasis is given to defining the inquiry approach and providing guidance in its utilization. This has been done particularly in the area of questioning. Detailed directions and examples are outlined illustrating how questions should be phrased to stimulate more thought, develop multi-talents, and science processes in both structured and unstructured inquiry situations. The reader is encouraged to follow the format of these lessons in creating his own inquiry-oriented materials such as: pictorial riddles, laboratory investigations, invitations, and evaluational instruments. It is our hope that prospective and experienced teachers will use these suggestions to develop better their creative potential. By so doing they will undoubtedly modify their instruction so that it becomes more student centered rather than teacher centered.

To this end, a chapter on Piaget's theory of cognitive development has been added. Piaget's research provides valuable insights into understanding why students of the same age differ in their abilities in solving complex problems, e.g., ratios and proportions. A student on the formal operational level experiences little difficulty in solving such problems, whereas, one in the concrete operational stage doesn't comprehend abstract mathematical concepts of this type. Teachers trying to treat their students humanely must endeavor to identify with the feelings and perceptions of their students and to see problems through their eyes. By so doing, they are better able to diagnose this type of learning difficulty. Piaget's work provides valuable assistance in better understanding why students have problems in performing certain types of logical and rational operations.

Presently there exists a controversy among educators over the use and desirability of behavioral objectives. Several states (Colorado, California . . .) have instituted accountability systems requiring teachers to design and use behavioral objectives. We believe the arguments on both sides have merit. However, because of the mobility of teachers and what appears to be a movement towards accountability by state legislatures and departments of education, teachers should know how to write and use behavioral objectives. To us the fundamental question is: "Do they help you become a better teacher?" If they do not or if you feel you have developed more effective procedures for achieving accountable teaching, use those methods most suitable to you.

All of the National Science Curriculum Projects are inquiry oriented. Many references and examples are provided to assist you in improving your own courses. While the work of many of the projects is finished, their impact in the 60s will remain for many decades. We have tried to highlight these thrusts to give new and experienced teachers bases for curriculum planning in their own schools.

In this edition, the higher levels of learning are emphasized, stressing in the various methods questions requiring critical thinking responses. The chapter on discipline in the previous edition has been well received. However, it has been modified here including more tested suggestions and hints of how to prevent and respond to discipline situations.

Science facilities continue to reflect advances in design and educational modes of instruction. The facilities chapter endeavors to reflect these changes. It continues to encourage flexibility and planning for the future rather than merely repeating traditional designs.

The evaluational chapter has been extensively rewritten to include techniques for evaluating the higher levels of the cognitive and affective domains, utilizing examinations, observational techniques, and self-evaluation inventories.

The chapter on creativity stresses the role of the teacher as a facilitator of this important human talent. Research results are outlined and many suggestions are given to help teachers become more creative instructors.

The authors have attempted to write a clear, practical book giving students sufficient philosophical and theoretical background to help them formulate their own theory of instruction. Much of the material in this text has been tested with prospective and experienced teachers. Valuable suggestions evolved out of our interaction with these individuals and where the text failed to achieve its intended purpose, the material was eliminated or revised and strengthened.

Both of us have had extensive experience in teaching in the public schools and in training science teachers. We have endeavored to translate this into a usable text and reference source for both the established and new generations of science teachers.

Our indebtedness to our colleagues and students increases daily. Teaching is a rich human experience causing all who participate in it to grow continually as teachers and persons. For us, it has been an endless challenge and a rewarding effort. We hope all who read this book will find the same type of excitement and thrill of professional satisfaction experienced by the authors.

Robert B. Sund

Leslie W. Trowbridge

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One of the great achievements of science is to have developed a method which works almost independently of the people whom it is operated on.
Aldous Huxley

1

What Is Science?

Before reading this chapter, define science in your own words without the assistance of any resources. Then share your definition with three other individuals and note their reactions. After doing this read the chapter and argue with it. Admittedly, a human endeavor as broad and divergent as scientific enterprise can hardly be covered in one chapter of a book. All that we hope to achieve by your reading it is to get you to think more about the philosophy of science.

After reading the chapter, try again to define science and compare this definition with your first one.

George Gelman walked into the classroom ready to meet his students on his first science teaching job. The teenagers soon filed in laughing and joking with one another. After the bell rang, Mr. Gelman proceeded in a halting manner to call the name of each student and several students helped him by repeating the correct pronunciations of their own names.

He then reviewed a few class procedures and began his first lesson, which involved a discussion of science and its contributions to modern society. The discussion moved rather slowly. The students were not eager on the first day in class to participate because they didn't know how the instructor would respond to their remarks. One girl raised her hand and asked, "Mr. Gelman, what is science anyway?"

What answer would you have given to such a question? A moment's reflection should indicate that this is not an easy question to answer.

What is science? *Science is both a body of knowledge and a process.* When a student says he is going to study science, he is going to investigate a particular type of knowledge. He is not going to consider music, art, or religion but rather such subjects as physics, chemistry, biology, or astronomy.

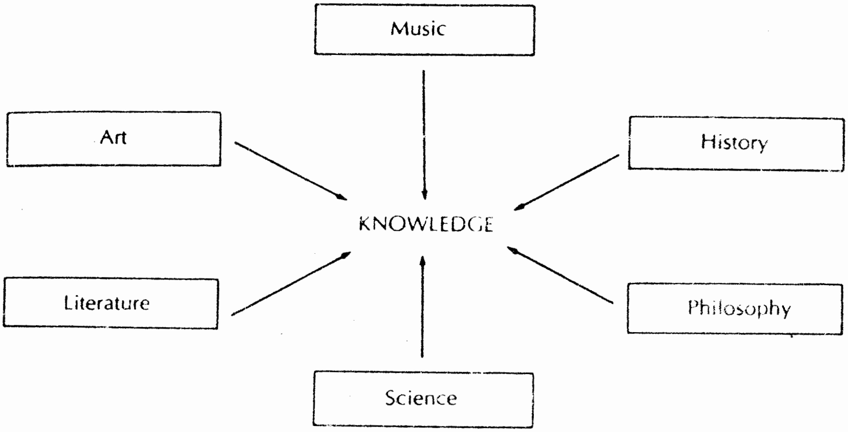

Figure 1

In the scientific subject areas knowledge is organized within various schemes or systems such as the theory of evolution, atomic theory, or cell theory. The key to whether a body of knowledge should be included under the heading of science is if it was discovered by the scientific method. If our awareness of a phenomenon is determined by use of such scientific processes as observation, measurement, experimentation, and other operations included in the scientific method, it is scientific information. This is true whether the information be about an atom, a flower, or a child's response to stimuli.

The product of scientific investigation is scientific knowledge. Unfortunately, it is this aspect of science that has mainly characterized science teaching. But science is more than just knowledge. It is human enterprise involving mental operations, manipulative and computational skills, and strategies, etc., that men devise to discover the nature of the universe. This human investigative aspect of science is dynamic since it evolves though the actions of men as they penetrate the unknown.

Scientists in their investigations behave in ways that vary from other human endeavors. For example, they formulate problems, hypothesize, design experiments, interpret data, synthesize theories, and define and obey rules of objectivity. These behaviors typifying scientists at work are called the *processes of science*. They are the vibrant condition characterizing science as it truly is in its research role. To think of science as only a body of organized knowledge is to concieve of it as being dead and ignores the human investigative excitement of men following the guide lines of scientific methodology in penetrating the frontiers of knowledge. Science as a human activity is alive. It is what men, scientists, do when they behave in the tradition of scientific investigation.

When a scientist questions, explores, and experiments, he demonstrates the inquiring nature of science. Unfortunately, a student can learn science as a body of knowledge without understanding it as a *process* and without knowing what inquiry involves. The recorded knowledge of science is *history* produced by men using scientific processes. Teachers have traditionally emphasized this product of science but have often failed to give students an understanding of the means of solving problems, one of the most valuable educative objectives for science instruction.

A SCIENCE DEVELOPS THROUGH SUCCESSIVE STEPS

As a specific area of science develops, it usually evolves through three distinct phases: observation, classification, and experimentation.

The Observation Phase

One of the first sciences was astronomy. It developed early because its objects—stars, planets, and the moon—could easily be seen. Bacteriology, on the other hand, could hardly unfold until man's senses were extended through such instruments as the optic and electron microscopes. The first phase of any new science is observational. It has to be, since something must be seen, directly or indirectly, before it can be studied and understood.

The Classification Phase

After a period of extensive observation, a science progresses to the second phase of its development—the classification phase. During the period of extensive Western exploration of the world, large numbers of new plants and animals were discovered, and many were brought back to Europe for further study. These had to be classified. In many cases, new categories were needed, and the need produced an improved system of classification. Whether working with rocks, trees, atomic particles, or stars, scientists eventually devise a classification system. This is done to facilitate storing knowledge in our minds or in books and other records and for retrieval purposes.

For example, if you were given the following problem, "Name ten characteristics of a Gnu, a mammal," you should have no difficulty even though you don't know what a Gnu is. All you have to know are the characteristics of mammals.

MAMMALS	
1. Have hair	6. Have a dorsal nerve cord
2. Have mammary glands	7. Have a dorsal aorta
3. Nurse their young	8. Bear their young alive
4. Have a four-chambered heart	9. Are warm blooded
5. Breathe with lungs	10. Have two sets of teeth

If mammals have these characteristics and a gnu is a mammal, it, therefore, has all of these characteristics. By knowing a classification system, you know an abundance of information. For example, if there are 30,000 mammals and you know these 10 characteristics are true for each mammal, then you know 30,000 times 10 or 300,000 facts. Knowing details of certain conventional classifications is also extremely important for purposes of precise communication. The use of a scientific classificational system insures accuracy because one name is given to each discrete item within the province of the system; no other object has the same name. Much more is involved in classification than is discussed here, but the point to remember is that all sciences involve intricate problems concerning classification.

The Experimental Phase

The last stage of any scientific discipline to evolve is its experimental phase; this is not to say that classification or observation ceases. Astronomy clearly has shown in its history the development of these three phases. During the periods of the ancient Egyptian, Babylonian, and Greek civilizations, many of the heavenly bodies were observed and recorded. This was the main observational phase of the science. The early astronomers soon discovered that planets, stars, and the moon differed from one another. They placed these in four groups: stars, the moon, planets, and sun. This was the classification stage of astronomy.

Finally, in the 1600s and 1700s relatively sophisticated discoveries were made about optics, light, and heat, and these eventually led to the laboratory experiments revealing that the color of a radiated body correlates with the amount of heat liberated. This knowledge, gained through research in the laboratory, was then applied to astronomy. Experimentation with and study of the phenomena of visible light, other radiation, and lenses, plus their applications to astronomy, began the experimental phase of the science.

Today sciences evolve with greater rapidity. As a consequence, in newly developing sciences these three phases of growth occur almost simultaneously. Almost all sciences that have existed for any length of time are now experiencing development in all three areas—observation, classification, and experimentation. Nevertheless, some sciences are still thought of as mainly observational, classificational, experimental, and some, such as those in certain areas of physics, lean heavily on mathematics for their insights into nature.

THE PHILOSOPHY OF SCIENCE

Philosophy has been defined as a study of truths underlying all knowledge. Dr. Robert S. Cohen defines it as a "persistent attempt to grapple with foundations."[1] Scientific philosophy concerns itself with how we come to know what we know about natural phenomena; it examines the processes and values by which science determines its truths. The philosophical foundations of science differ from other philosophical views.

Science Obtains its Truth Empirically

Dr. Joseph R. Royce[2] has outlined in Figure 2 the ways in which man looks at reality. Study the chart and note the four philosophical approaches represented.

Figure 2 indicates that science basically determines its knowledge by empirical means. Empirical data are obtained by a scientist's feeling, touching, tasting, or using other senses to collect information. Thus, the key to the empirical approach is that it is based on *observation*, either

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[1] "Individuality and Common Purpose, the Philosophy of Science," *Science Teacher* (May 1964):27.

[2] Joseph R. Royce, "The Search For Meaning," *American Scientist* 47 (1959):4.

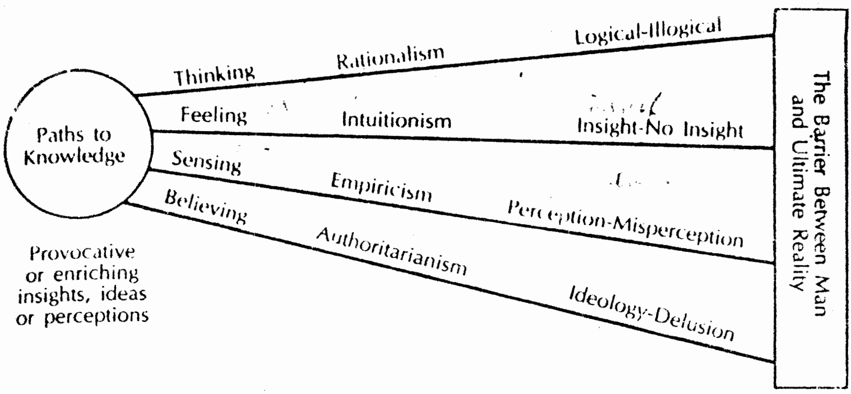


Figure 2 *The Basic Paths to Knowledge*

directly or indirectly through the use of apparatus; much of the effort of the scientist is actually devoted to observing and measuring phenomena more accurately so as to obtain better empirical data. Logic and reason are naturally involved in any experimental effort, but science does not accept truths solely on the basis of logic unless they can be verified by some empirical means.

Theology's Truth Is Based on Faith

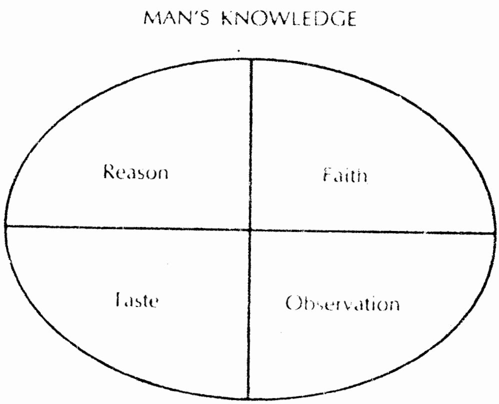


Figure 3 *Individual Man's Knowledge Comes from Faith, Reason, Taste (Esthetics), and Observation (Empirical Evidence)*

Refer to Figure 2. Which of these lines is used as the basis of theology? It should be obvious that it is mainly logic and faith—authoritarianism. No one would think of trying to prove the existence of God by performing an experiment. There is considerable confusion today because of a lack of understanding of the various philosophical means by which man attempts to know his place in the universe. No man is purely empirical in his daily life. *An individual consists of components of all of these approaches* to knowledge since he thinks, feels, senses, believes, and accepts some things on faith. If you understand this, you are likely to comprehend why science and religion fundamentally are not in conflict. A scientist doing scientific research must base his work upon empirical data, but as a man living outside his laboratory he may often manifest other philosophical views such as those of theology.

Note that Figure 2 further indicates that man seeks truth through several paths and since there are different routes to knowledge, they are not in conflict. Conflict may occur, however, when an individual tries to substantiate a religious philosophical view based on faith with empirical evidence.

SCIENCE IS MECHANISTIC, NOT VITALISTIC

The empirical approach of science is based upon the assumptions that the universe is intelligible; man can study nature and discover natural laws; there is reality to space, time, and matter; and all natural phenomena can be explained in terms of physical and chemical states. Describing nature in this manner is said to be a mechanistic as opposed to a vitalistic approach. Vitalists do not believe that man can discover all the basic forces of nature and life; they think there is a secret vital entity man will never be able to discover. For example, vitalists believe scientists will never be able to create life in test tubes because they will not be able to isolate the vital entity necessary for life.

CAUSE AND EFFECT

Scientists generally believe that for every change or effect there is a cause; this view is held consistently in science except for some special cases in physics. Much of scientific research is involved with determining causes: What causes cancer? What causes metals to expand? What causes leaves to fall? Science is also interested in effects: What energy is released when the atom is split? What are the effects of smoking? What is the effect of taking too many aspirins? Scientists do not believe that changes occur because of some mysterious magic. They believe that all physical and biological changes can be understood, the causes of change determined, and the effects of change predicted.

Statistics and the laws of probability are often used to determine cause and effect relationships. Statistical correlations, in medicine, education, psychology, etc., are used as means of relating cause with effect. For example, statistics indicate people who smoke have a high incidence of lung cancer, emphysema, and cardio-vascular disease as compared to nonsmokers. Although the correlations are very high and seem to indicate that smoking is related to these diseases, the statistics do not prove it to be. Statistics are only tools of the scientist. To prove that smoking actually causes these diseases scientists would have to isolate the agents causing the diseases, give them to a random sample of people, and see if they developed these diseases. For humane reasons, it is likely that scientists will not use people but other animals. Some statisticians argue that the reason that this high correlation does not prove a causal relationship is that the kind of person who chooses to smoke is by nature more susceptible to these diseases. Smoking types of people are different from nonsmoking types. However, when continued analyses are provided and higher correlations are obtained, more and more individuals will undoubtedly believe that agents in cigarettes are the cause behind these maladies. A correlation, therefore, does not necessarily indicate a cause is linked to a specific effect. The scientist must question if it is reasonable and often search for further evidence.

SCIENCE DOES NOT EXPLAIN PHENOMENA IN TELEOLOGICAL TERMS

Often students describing the reasons for change do so in teleological terms. Teleology is defined as the doctrine of final causes; the word *telos* in Greek means *end*.

Gary, a tenth-grade student, placed a plant near a window. He noticed that after several days it bent toward the window. When the teacher asked why, he answered, "It bent because it wanted to!" This is a teleological type of explanation. It implies that a plant has an end in mind: to bend toward the light. Where is the "want" part of a plant? If Gary had understood the meaning of a mechanistic explanation as used in science, he would have replied instead, "The plant bent toward the light because there is something stimulating the plant causing the plant to modify its growth in that direction." The reason scientists do not explain things in teleological terms is that this type of description does not contribute to better understanding of what occurred. On the other hand, a mechanistic explanation is more likely to suggest paths for further research. Teleological explanations, because of their vagueness, fail in this respect.

SCIENCE FRACTIONATES

In doing scientific research, the scientist often works with isolated factors. He does not start on a problem involving the entire universe but rather studies the sun or attempts a less involved study such as an analysis of the wave lengths of light coming from the sun. In order to understand a complex entity, the scientist often breaks it down into parts and researches these. With the information gathered from his studies he may then generalize. For example, in studying the nature of the universe the scientist studies the sun, then generalizes from information gathered about it to other stars. Essentially, the scientist divides the whole into bits for study and then puts these bits together to understand the whole. In studying man, the scientist studies the anatomy and physiology of several men. From his research data on these men he may generalize about the characteristics of all men. This approach presents certain problems, since the whole may not be simply the sum of all the parts, but the approach does allow a formidable problem to be reduced so scientists can answer fundamental questions about it. On the other hand, there are scientists who do not operate in a fractionating way. They are the great synthesizers who somehow obtain insight that brings to their minds great generalizations—theories. Once they get such an insight, they set out to prove or disprove it. These men are the dynamic, theoretical creators like Copernicus, Kepler, Pasteur, Koch, Einstein, etc.

THE GOALS OF SCIENCE

Theories and Scientific Principles

One purpose of science is to produce principles and theories. A principle is a rule or law about natural phenomena, for example, "Metals expand when heated;" "Cells arise only from the division of other cells;" "Light is refracted toward the normal when it passes from less dense to more dense media."

A theory is more inclusive than a principle. 1) A theory is a more or less verified explanation accounting for facts or phenomena and specifying relationships between groups of empirical data. 2) A theory has explanatory, predictive, and organizational value. For example, if you have obtained several skeletons from various strata in the earth, you will have to memorize from which level each skeleton came; but if you know the theory of evolution, you can order these skeletons (assuming they are related) and know which skeleton was obtained from the lowest stratum and the sequence of the rest of the skeletons. Knowing a theory of evolution aids you in understanding the relationship of the skeletons and explains their association. Knowledge of evolution helps us organize our information and makes it possible for us to make predictions.

Knowing the theory of evolution enables the scientist to predict the kind of skeleton that might be found at a lower stratal depth. Atomic theory, cell theory, germ theory, and theory of evolution are but a few of the theories devised by man. A moment's reflection on their value certainly indicates why science endeavors to create these orderly explanations.

Theories are based on facts which are derived from observation and experimentation. As our experimentation progresses and reveals new information, theories often have to be modified. Scientists search for theories and principles which are true and unchanging, but the history of science has shown that there is no certainty in science but only probability. Because theories evolve and are modified as our knowledge of nature increases, the goals of science in formulating broad, encompassing ideas of knowledge—theories—never ends. There is always an assignment for the next generation.

With this realization, a scientist is humble about what he knows and thinks he knows. At first thought, it seems that the futile search for certainty would be frustrating, but there is joy in the discovery that knowledge is unending. There is always more to do and learn and more problems to solve. Life itself is a process of solving problems, and a scientist enriches his life and his self-concept by being involved in problems of value to all men.

RESEARCH

Students often confuse science with research—not all science is research, as was previously indicated in this chapter. Research may be defined as

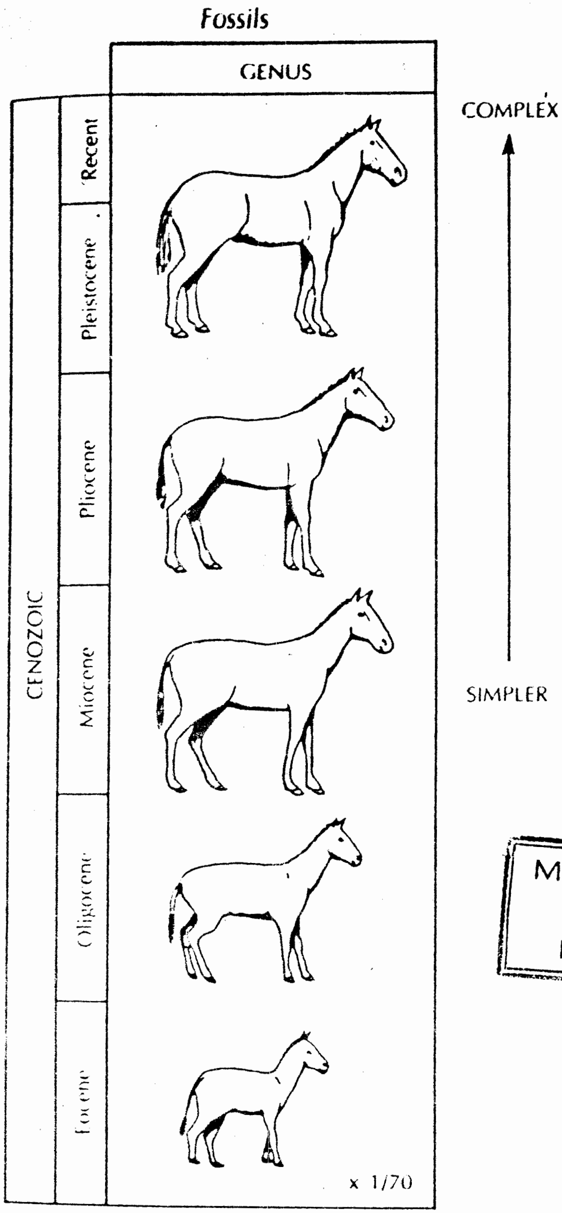


Figure 4 *A Theory has Organizational Value*

an attempt to collect unbiased information about observed phenomena. Research implies active involvement in the solving of a problem not previously answered by man. A student may follow scientific procedures in solving a problem, the answer to which he does not know; however, if the answer has been determined previously by a scientist, the student is scientific but he is not doing research. Since man is often biased, the scientific processes have been devised to insure that he is objective in his decision making and in his approaches to a problem. It would seem to be easy for a novice to do research, but the untrained mind seldom has learned the techniques of guarding against unbiased decisions. Training in the processes and techniques of solving problems intelligently requires a long period of education but one having value beyond calculation.

METHODS OF REPORTING SCIENTIFIC INFORMATION

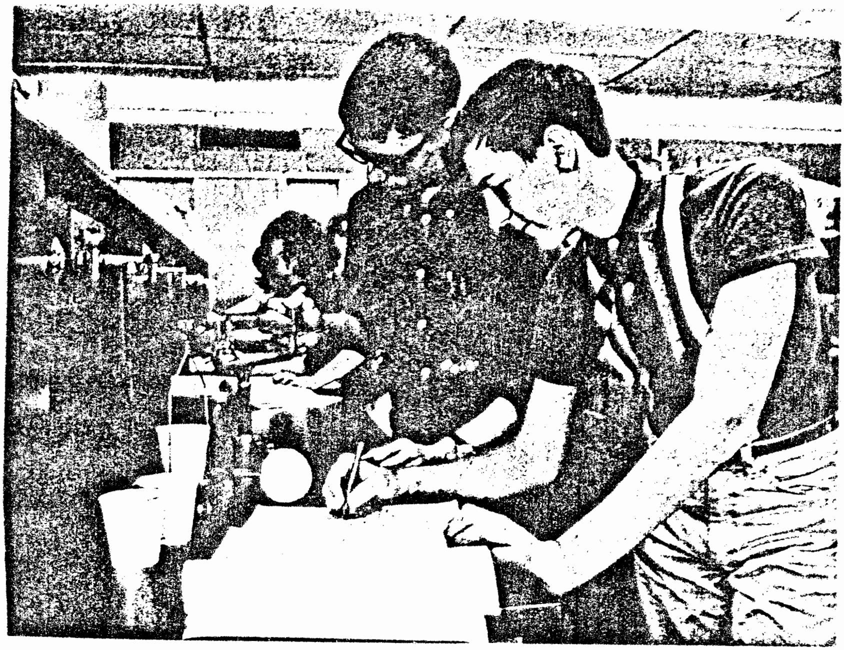
Often teachers have had their students memorize a list, reproduced below, of the steps in the so-called scientific method, with the aim in mind that once the students have memorized these six steps they will be "scientific."

Scientific Method

1. Stating the problem
2. Formulating hypotheses
3. Designing an experiment
4. Making observations
5. Collecting data from the experiment
6. Drawing conclusions

Nothing can be further from the truth. These six steps actually are the way scientific information is reported. A scientist when solving a problem will perform all of these steps but not necessarily in the order given. He may have to define and redefine the problem several times and make several hypotheses (good, critical guesses) as to the solution to the problem.

Memorization of the list in no way helps an individual make hypotheses, sort problems, collect data, and draw conclusions. How does one collect data? What is the research design? What kind of variables must be considered? All of these questions and more are involved in doing research. Simple memorization of the six steps is of little help in understanding the processes of science. The only way to learn football is to play it, and so it is with science. The only way a student learns to be scientific is to be placed in situations where he is actively involved in using scientific methods. Try to explain football to a foreign student, and you will soon see how futile it is. You can explain certain fundamentals, and knowledge of these is helpful; but the way really to understand the game is to become a player on a team. By analogy, the science student must be a player on the scientific team.



What are the learning possibilities shown in this picture?

Courtesy of Bob Waters, University of Northern Colorado

SOCIAL IMPLICATIONS

Many scientists and other citizens are becoming increasingly concerned about the social implications of scientific enterprise. Scientific investigation endeavors to reveal truth. What it reveals, however, can be used for the benefit or detriment of our fellow man. Madame Curie, for example, did not know beforehand the value or the danger of discovering radioactive material. Nuclear research has been used to cause cataclysmic harm to the people of Hiroshima and Nagasaki. Radiation has also been used for the benefit of man, i.e., to treat cancer. Madame Curie died of cancer.

Clearly the scientific community is becoming more allied in its insistence that science be dedicated to using scientific enterprise for the benefit of man. The National Biology Teachers Association, for example, recently sponsored a national convention in which the social implications of science was the main theme.[3] There is an increasing number of scientists trying to educate the lay public to the problems of the population explosion, pollution, insecticide poisoning of the environment and other ecological concerns. The emphasis is towards building and maintaining a beautiful environment. This message has tremendous appeal for our young people and can be used as a valuable means of involving them in scientific investigations particularly if they are related to the local environment. Clearly the responsibility of teachers is to show students that scientific discoveries can help to prevent the destruction of the environment. It must be remembered, however, that many young people think of scientists as the atomic bomb builders, producers of chemicals that cause havoc in war, etc. These students must obtain a more realistic view and realize that they can be instrumental in seeing that scientific discoveries are used for the benefit of man. No scientist can know how valuable his discovery will be before he makes it. But, all citizens can be insistent that the scientific discoveries be used to improve the earth's environment and produce a better life style.

SCIENTIFIC INVESTIGATION IS A HUMANISTIC ACTIVITY

Scientific investigation is done by men. It is a human enterprise against the darkness of ignorance and it requires creative genius. Scientists are alive; they are people with psychological motives and needs like other people. The product of their endeavor is scientific knowledge. This knowledge is revealed because of their activity—a human endeavor. Inquiry into the unknown through creative enterprise combining the talents and the labors of countless men characterizes modern science. Consider

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[3]For an excellent discussion of the main ideas of the convention read *Social Implications of Biological Education*, Edited by Arnold B. Grobman, National Association of Biology Teachers, Washington, D.C., 1970.

for a moment all the efforts of men throughout the world to unravel the complex problem of cancer in India, China, Japan, Russia, Mexico, Peru, Canada, and the United States. Nationalities fade in the free interchange of their research efforts. These are men fighting an evil for all mankind. Science is truly humanistic since it is done by men and often historically demonstrates the best cooperations between men ever evidenced on this globe.

IMPLICATIONS OF SCIENTIFIC PHILOSOPHY FOR TEACHING SCIENCE

Prospective teachers seldom have had research experience in science. Their college courses traditionally have offered little opportunity for them to devise an experiment or solve problems other than those of a cookbook type. Their science instruction usually has emphasized the products rather than the process of scientific research. As a result, they have generally prepared for their science classes by memorizing material. Memorization tends to emphasize the learning of words, a skill which many can acquire without learning to be scientific. Because prospective teachers have been trained in this manner, they often mistake learning scientific words for an understanding of science. After being employed as teachers, they have emphasized memorization of terms, assuming that if a student knows scientific terms he will have more understanding of science. *Teachers have falsely assumed that learning the products of science will enable a student to use the processes of science.* Many scientists and science educators have become concerned with this outlook and have made efforts to produce courses and curricula giving greater attention to the understanding of science as a process. Teachers, as a consequence, have had to become more aware of the inquiring nature of science and have had to communicate this awareness to their students.

Teaching the inquiring aspects of science requires greater understanding of scientific philosophy and considerable skill to implement it in the classroom. It is easy to pour out the facts of science — the product — but it is difficult to teach students to solve problems scientifically. A teacher who understands the philosophical bases of science and incorporates this understanding in his instruction is more likely to lead his students to modify their behavior to face problems in a scientific manner, not only in the laboratory but in life situations as well.

CONCEPT FORMATION

In addition to teaching problem-solving skills, science instructors are essentially involved in teaching scientific concepts and principles. Yet, few teachers understand well concept formation and its place in mental growth.

We learn all empirically based knowledge from our senses. The starting of knowledge then must be a perception of a phenomenon in nature. A child feels, touches, tastes, and smells. He is enraptured with the information his senses send to him. Out of these he then passes from perceptual awareness to conceptual understanding. This is no easy mental jump. Older children, too, have to go through the same stages of mental activity before they begin to understand and gain meaning.

What is a percept and how are percepts related to concepts? A table you see is a percept; you perceive it. If you are asked to draw a table, this is quite a different story. What you have to do in order to draw a table is to know what makes tableness. Think for a moment of a child trying to learn the word *table*. Better yet, ask several students to draw a table on a piece of paper. They will draw all kinds of variations.

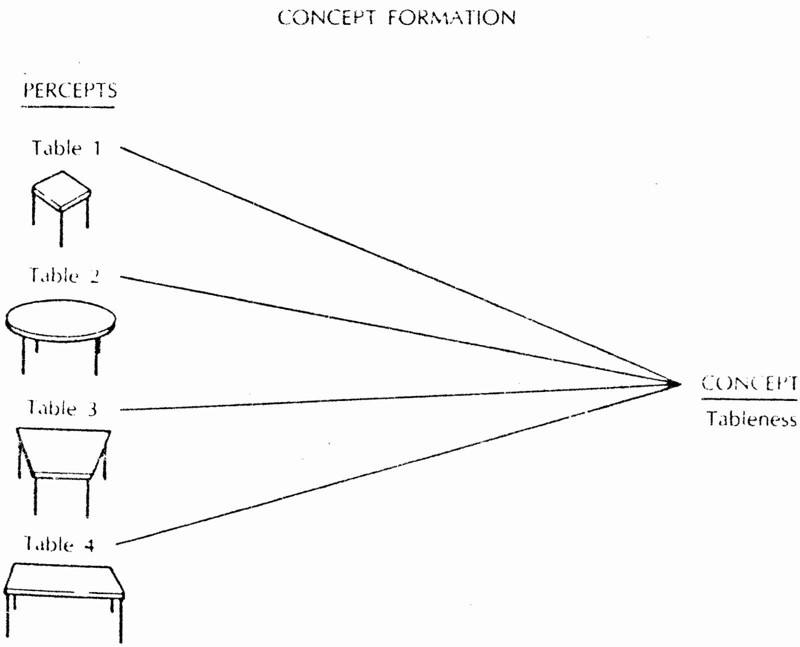


Figure 5 *Concept Formation*

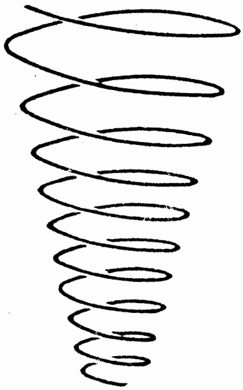
Their tables may have one, two, three, four, or six legs. They may be round, oblong, hexagonal, square, or triangular; or some students may even draw a mathematical table. What makes a table a table? How does a child ever get to know the essential qualities of a table? He must have many perceptions of many tables before he abstracts out of these the essential qualities of tableness. After doing this he has formed a mental abstract called a concept; he has a mental picture of a table in his mind.

Percepts Make Concepts

A person's conceptual view never ceases to grow. It expands with knowledge and experience. Think again of the child who develops the concept *of table*. As he goes through life he will see an infinite number of variations of tables, and his understanding of tableness will evolve and increase.

Now think of a complex biological concept such as *cell*. How would you start a lesson to develop an understanding of the cell theory? What concepts are involved? Obviously you would have to teach what a cell is, but how would you start? If learning commences by perception, then there should be several opportunities for students to see cells. The more types of cells they see, the better will be their concept. The traditional statement, "A cell is a basic unit of life containing a nucleus," is a far cry from what a cell is. A teacher who has students just read about or see a film about cells is building a low level of concept formation, but a teacher who has students actually see and experience cells is building not only better conceptual understanding but more lasting learning. There is no end to developing the meaning of *cell*. Compare a tenth-grade biology student's conceptual view of a cell with that of a biochemist or a cytologist. The tenth grader sees a cell as a flat, round, or oblong small object. The biochemist sees it as a dynamic biochemical complex, constantly changing, using and storing energy. As we live we discover new concepts and increase the horizons of our old ones. Figure 6 depicts mental growth. Notice that as a child grows into adulthood his conceptual growth starts with concrete perceptions and spirals to successive levels of broadened conceptual abstraction.

A teacher, however, must be aware that there are two main types of concepts, those involving abstractions derived from concrete objects —such as *cell*—and those involving process—such as the kinetic theory of matter, induction, or photosynthesis. Process abstractions are generally harder to teach. They require far more preparation by the teacher. The student must have many experiences before he truly gains insight into their operation. Never assume that because a student can memorize a process and parrot this back to you that he understands it or has much meaningful insight into its operation. Cronbach says, "The depth of understanding, the range of application of a concept, and the precision with which it is used can grow for years after definition is learned."[4] As an individual grows older he reconstructs his previous conceptions on even higher levels of abstraction and thereby increases his wisdom.



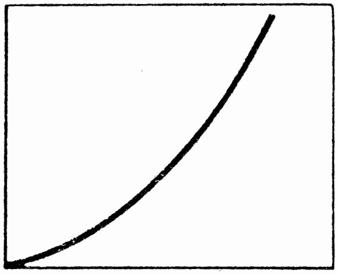


Figure 6 *Broad Abstract Conceptions*

TYPES OF CONCEPTS

CONCRETE CONCEPTS	DYNAMIC PROCESS CONCEPTS
Magnet	Osmosis
Lens	Acceleration
Colloid	Precipitation
Metal	Photosynthesis
Rock	Fission
	Aging

Note (Figure 6) that mental growth does not occur in a pattern one might represent by a straight line graph. There are stages in the life

[4]L. J. Cronbach, *Educational Psychology* (New York: Harcourt Brace Jovanovich, 1963), p. 356.

of an individual when he must build a wealth of experience and must mature before he ascends into the next level of mental development and becomes capable of forming complex conceptualizations. Figure 7 shows how a concept of a cell may advance through successive stages—and some of the possible misconceptions students may develop.

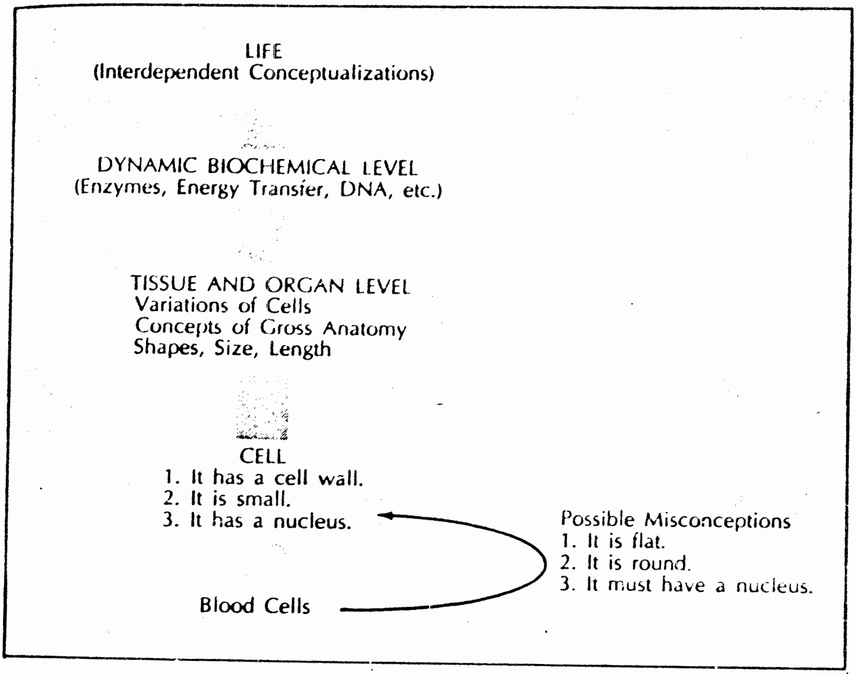


Figure 7 *Where Does a Concept Begin and Where Does it End?*

Science teachers are interested in teaching the principles of science because these prepare an individual to operate effectively in his environment. Bruner says, "An understanding of fundamental principles and ideas appears to be the main road to adequate 'transfer of training.' You learn a model for understanding other things." He further states:

> We remember a formula, a vivid detail that carries the meaning of an event, an average that stands for a range of events, a caricature or picture that preserves an essence—all of them techniques of condensation and representation. What learning general or fundamental principles does is to ensure that memory loss will not mean total loss, that what remains will permit us to reconstruct the details when needed. A

good theory is the vehicle not only for understanding a phenomenon now but also remembering it tomorrow.[5]

How can a teacher use a climatorium to stimulate learning?

Courtesy of Newark School District

WHAT ARE SCIENTIFIC PRINCIPLES, AND HOW CAN WE TEACH FOR THEM?

Figure 8 indicates that through percepts, concepts are learned; and concepts make principles.

A science teacher tries to have students learn the principles and theories of science. In order to accomplish this end, the teacher must constantly give students perceptual experiences, building concepts that are necessary to understand principles. There is no end to understanding and learning how, when, and where to apply principles. This is a lifelong activity. All science instruction, if possible, should start with a percept, something a student can see, taste, touch, or smell. At least

[5] J. Bruner, *The Process of Education* (Cambridge, Mass.: Harvard University Press, 1960), p. 25.

at this point students are with the instructor in the learning process. At no other place in your teaching can you be sure of where students are in their conceptual understanding.

If a tenth-grade biology teacher wants to teach the principle "The basis of all life is the cell," how should he start to teach for real understanding of this principle? The conceptual frameworks *life* and *cell* are necessary before the meaning of the above statement can be realized. Consider another principle: "Metals when heated expand." To comprehend this, a student has to know the meanings of *metal, heat,* and *expansion.* These are difficult concepts to teach, but they involve thrilling teaching challenges. When a teacher looks at the design of his lesson plans through the percepts-concepts-principle organization, he has better direction and is more assured of his effectiveness as a teacher.

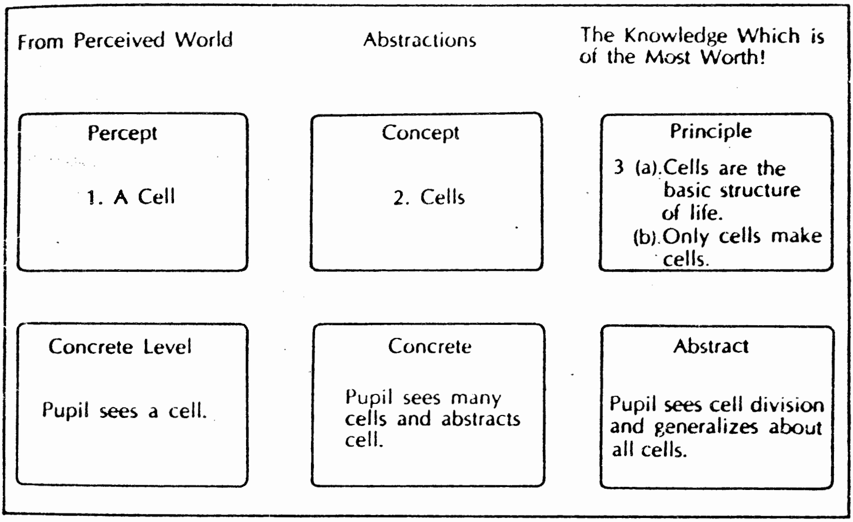


Figure 8 *Concept Formation*

SUMMARY

Science is both a body of knowledge and a process; the body of knowledge is the product of solving problems scientifically. A new science develops through successive stages. These stages are observation, classification, and experimentation. Some sciences, however, are mainly observational, while others may be classificational or experimental.

The philosophical basis of science is distinguished by its approach to the discovery of knowledge. Science bases its truths upon empirical (observational) data derived from observations of natural phenomena. Science is mechanistic, since it describes causes and effects in physical and chemical terms; teleological explanations are discouraged in science because they are vague and give little direction for further research.

Scientists are concerned with "what" and "how" questions; "what" questions require descriptive answers, and "how" questions usually involve process answers. Theologians, on the other hand, try to answer "why" questions. Since science and religion don't ask the same questions, they are generally not in conflict.

A scientist studying a complex problem often breaks it down into parts. He fractionates the problem in order to study it and then generalizes, from these parts, about the whole. He does research to discover scientific principles to formulate theories about nature. The scientist accepts a specified way in which to report scientific research. The method of reporting research, however, is not necessarily the way the research was actually done.

Teachers have traditionally emphasized the product rather than the process of science. This has been done because teachers have not had a good understanding of the philosophical bases and processes of science.

In addition to teaching scientific investigative processes, science instructors also teach the concepts, principles, and theories of science. To understand a concept, a student must have experienced many relevant percepts. Through perceiving several tables, for example, the young child slowly abstracts mentally the concept "tableness." Science teaching should proceed by giving students many opportunities to perceive (percepts)—magnets, lenses, salts, cells, elements, etc.—so that students gain a sound basis for forming concepts and principles in their minds. The understanding of these forms the foundation for learning and comprehending the broad conceptual schemes of science — theories.

Further Investigation and Study

1. How would you explain to tenth-grade students the meaning of science? Can they derive much understanding from an explanation?
2. What are the various ways man discovers knowledge? Why aren't they necessarily in conflict?
3. How does empirical data differ from other information?
4. A student says he thinks it is going to rain; another student asks him if he has empirical evidence for that statement. If the first student says yes, what evidence do you think he has?
5. Plato thought that the ultimate reality was in the mind. For example, a perfect circle was an idea in the mind of man. How does scientific philosophy differ from the Platonic view?
6. How would you explain scientifically the blooming of a flower? How would you do it teleologically? Show how the scientific explanation helps you to suggest an experiment related to blooming.
7. What is meant by the statement, "Science fractionates"? What dangers are involved in breaking problems into small parts and then from the research on these parts generalizing about the whole?
8. How has the reading of this chapter modified the way you will teach?
9. Why should a science teacher read about the philosophy of science?
10. A teacher had her students memorize this list of the six steps of the scientific method:

    1. Defining a problem
    2. Making an hypothesis
    3. Devising an experiment
    4. Making observations
    5. Collecting data
    6. Drawing conclusions

    After several weeks, the teacher gave the class a problem. She was amazed to find out that they didn't know how to solve it. What explanation can you give for the students' behavior? How would you have taught to insure better problem-solving competence among the students?

11. Refer to the quotation by Aldous Huxley at the beginning of this chapter. What does this statement mean?
12. Give an example of a percept, concept, principle, and a theory.
13. If you were going to teach a unit on photosynthesis in junior high school knowing what you do about concept formation, how would you start it?
14. How would you start a unit on electricity and why?
15. It has been said that to an educated man concept enlargement never ends. What does this mean to you?
16. Educational research indicates that if students understand scientific principles their retention of these is high even years after they studied them. How would you insure that students understand the principles they are learning?
17. How do you feel the reading of this chapter has affected you as a teacher?

If learning actually took place as teachers believe it does, we could master almost anything overnight.
*William Burton**

A man without a theory is doomed to make the same mistake twice.
Disraeli

2

Toward a Modern Theory of Instruction

The teaching profession is fundamentally concerned with the attainment of maximum beneficial learning for the individual. A teacher's role is to insure that learning is efficient and effective in order for students to discover their human potential. A good teacher asks: "How well have I organized the activities for my class? How have I allowed for the involvement of students in planning class activities? How effective is this lesson, demonstration, film, text, or program? How do these lessons contribute to the growth of better persons?" In answering these questions, the instructor relies on his training in subject matter, educational psychology, and life experiences.

The problem of stimulating students to be thrilled with learning and gain a zest for education that will continue for life is a large task. The greatest fringe benefit for a teacher is that there is so much to know and learn about academic subjects, human behavior, and how to become an effective instructor that the work is never done. Routine causes boredom. In teaching there is little room for routine since the challenge to maximize

*William Burton, *The Guidance of Learning Activities*, (New York: Appleton-Century-Crofts, 1962).

the potential of each individual requires constant adaptation and innovation by the instructor.

Scientists endeavor to construct theories. They use these as guides contributing toward insights into the intricacies of nature. A theory is a fantastic intellectual instrument economizing the chores of the mind; for, by knowing relatively little—a theory—the mind knows much. It is through theoretical understanding that a person is capable of interpreting volumes of information.

Just as the task of a scientist is to formulate and evolve theories, so must teachers build through their teaching life span an instructional theory helping them to predict, explain, and organize learning. Beginning teachers start with but a few fibers entwined into a weak theoretical structure, but as they progress through an infinitude of experiences, awarenesses, and learnings about human behavior, they slowly fashion an instructional theory that works best for them. A teacher's instructional theory is never complete because as he grows and gains insights into human behavior, he evaluates, modifies, and builds his theoretical framework.

What are the origins for his theoretical construct? Much of it must come from what is known from the behavioral sciences plus what the teacher discovers in a pragmatic way in his own classroom—what works for him with his students is what counts. Just as the sciences have their scientific principles so have psychology and sociology established certain principles. Education applies the principles revealed by psychology and sociology to the field of learning. An effective teacher is aware of the knowledge of these disciplines. Science teachers have taken courses in educational psychology to learn principles of human behavior and theories of learning, but this knowledge is of value only if it can be translated into action in the classroom. It is then that the prospective teacher is truly evaluated, not by his professors but by his students.

The following sections discuss both principles of learning and principles of teaching which have great implications for science teaching. As you read about these, think of how you would use them as guidelines in your teaching. Imagine your own class, your teaching, your students, class episodes, and how you would operate as an effective teacher. To memorize a psychological principle takes little intelligence, but a principle can be well applied only by a truly intelligent and gifted person. From the day you start teaching to the day you retire you will be trying to apply principles of learning successfully in your instruction.

In the sections below no attempt has been made to present an exhaustive catalogue of principles but only a helpful list for the prospective teacher.

PRINCIPLES OF LEARNING

1. Students learn best by being actively involved. If they can do an experiment themselves rather than read about it, they will learn better.

2. Positive, or reward, reinforcement is more likely to result in students' learning than negative reinforcement. A teacher who compliments and encourages students is more likely to obtain higher achievement than one who tells them their work is poor or derides them for poor achievement. Threat or punishment may cause avoidance tendencies in the student, preventing learning. Some failure can best be tolerated by providing a backlog of successful experiences.

3. A situation which offers fresh and stimulating experiences is a kind of reward that enhances learning.

4. Learning is transferred to the extent the learner sees possibilities for transfer and has opportunities to apply his knowledge.

5. Meaningful material is easiest learned and best retained.

6. Learning is enhanced by a wide variety of experiences which are organized around purposes accepted by the students. Teach in depth. Don't try to cover the book; cover what you do well, giving opportunities for students to have many experiences with the subject.

7. The learner is always learning other things than what a teacher thinks he is teaching. A teacher may have a student heat a chemical solution to get a precipitate. The teacher is teaching a chemical process; but the student is also learning laboratory skills and how to organize the equipment, be efficient in the laboratory, and work with others. None of these is likely to be tested in an examination.

8. Learning is increased when provided in a rich and varied environment. The richer the classroom, laboratory, and school surroundings in offering opportunities for learning, the greater the level of achievement. A bare, uninteresting room offers little stimulation for learning.

9. Detail must be placed into a structured pattern or it is rapidly forgotten.

10. Learning from reading is increased if time is spent on recalling what has been read rather than on rereading.

TEACHING PRINCIPLES

1. Planned teaching results in more learning.

2. Students tend to achieve in ways they are tested. If you test only for facts, they tend only to memorize facts.

3. Students learn more effectively if they know the objectives and are shown how to gain these ends. Science teachers should spend time

discussing the purposes of doing experiments by inquiry and the processes used in solving problems.

4. The teacher's function in the learning process is one of guidance, guiding individuals to reach an objective.

5. Pupils learn from one another. Working in groups in the laboratory can enhance learning.

6. When the understanding of a detail of any theory or apparatus is determined by the whole, then the comprehension of that part must wait until the whole is understood. A teacher doesn't teach about the histology of the body until a student knows about the body's general anatomy.[1]

A situation which offers fresh and stimulating experience is a kind of reward and enhances learning.

Courtesy of Harold Pratt, Science Supervisor, Jefferson County, Colorado

CHARACTERISTICS OF AN INSTRUCTIONAL THEORY

In interacting with students, teachers must constantly check back in their minds with these principles to see whether they are applying th

[1] For verification and discussion of these principles consult educational psycholog

to the classroom. It is easy for a teacher to know the principle, "The greater the student involvement, the greater the learning," and then turn around and do harm to this principle by lecturing to students, thus providing little involvement. The effective teacher knows the principles and translates them into action.

Some years ago Dr. Jerome S. Bruner wrote a book entitled *Toward a Theory of Instruction* in which he outlines the nature of a teaching theory. He thought an instruction theory should have six characteristics. These are, in slightly modified form:[2]

1. *Prescriptive.* It gives direction concerning the most effective way of achieving knowledge.
2. *Normative.* It establishes criteria for determining what is to be learned and describes the conditions for achievement.
3. *Motivating.* It specifies experiences that affect a person's predisposition to learn.
4. *Structured.* It specifies how the body of knowledge should be structured so individuals learn it effectively.
5. It describes effective sequence.
6. It outlines the role of pacing rewards and punishments in the process of learning.

An instructional theory is an inclusive explanation encompassing all principles of learning. It is a general guide for every aspect of teaching.

BUILDING "SELF-CONCEPTS"

The fundamental task of becoming an excellent teacher is to build a theory that will help you to this end. Teaching can be exciting because it provides a humanistic laboratory where a teacher can sculpture himself through interpersonal interaction into a better person. We feel education has fractionated, divided, and isolated many of the important components that go into teaching students successfully. Unfortunately, the teacher-preparation programs have emphasized these components: "If you are well planned...," "If you use this curriculum...," "If you understand the child's cognitive stages...," etc. These are important, but they are means, not ends. The results of this atomistic view of education has been: The neglect of the primary and crucial variable in the class-

[2] Jerome S. Bruner, *Toward a Theory of Instruction* (New York: W.W. Norton and Co., 1968).

room, the teacher as a person; a view of the student that is fractionated; and an emphasis on planning, procedure, methods organization, and subject matter.

A few years ago the Association for Supervision and Curriculum Development published a book entitled *Perceiving, Behaving, and Becoming: A New Focus for Education*. It outlined a general theoretical structure for becoming a fully functioning person and described the implications of this view for teaching. The book was authored by Earl C. Kelley, Carl R. Rogers, A. H. Maslow, Arthur W. Combs, plus many others, and is mainly concerned with providing teachers with a humanistic theory of instruction. This view of psychology looks at individuals as functioning organisms each in the process of trying to build his self-concept. This humanistic approach centers on the individual teacher as a person rather than a giver of knowledge. The ways the individual views self, others, and the teaching task are the foundations on which the instructional theory is constructed. The teacher's perceptions, beliefs, and values guide his interaction with students, selection of curriculum materials, and organization within the classroom. Some of the main tenets of this theory are:

1. The perceptions an individual has at any given moment determine his behavior.
2. Perceptions about self are more important than other existing perceptions.
3. Man is always engaged in a continuous striving for self-fulfillment.[3]

These principles do not emphasize one particular domain of education, i.e., cognitive, affective, or psychomotor, rather *all* domains are integrated under the three principles.

The role of a teacher under this theoretical framework is to continually do things to help students build their self-concepts. This means the teacher involves students in the learning process so that they have successful experiences, feel accepted, are liked, respected, admired, etc. The theory stresses the necessity of perceiving well the individual on his way to becoming a person and personalizing the learning environment. This means the instructor must treat every person as an individual with particular needs at a specific place in time on his path to "becoming." The teacher helps him *become* by being open, non-

[3]Arthur W. Combs, *The Professional Education of Teachers* (Boston: Allyn and Bacon, 1965).

threatening, and accepting, by liking him, reducing fear, and helping the individual discover his identity by building his self-concept. As an individual becomes more secure through acceptance, he is more willing to take risks, and, by so doing, he is more likely to be creative. And, being creative is truly a valuable human characteristic. In these times when so many of our students seem to have problems with their identities and self-concepts, the humanistic approach provides an excellent psychological foundation for helping them resolve these problems. Maslow says: "Every person is, in part, his own project and makes himself."[4]

How is humane teaching demonstrated in this photograph?

Courtesy of Harold Pratt, Science Supervisor, Jefferson County, Colorado

Outstanding Teachers Relate Well with Students

When students are given the opportunity to identify the characteristics of outstanding teachers, they seldom list as paramount in importance subject matter competence. Rather students believe good teachers project humanness and believe it is more important that an instructor relate well and interact in an enthusiastic manner with them. This holds true

[4] A. H. Maslow, "Some Basic Propositions of Growth and Self-Actualization Psychology," *Perceiving, Behaving, Becoming: A New Focus for Education* (Washington, D.C., Association for Supervision and Curriculum Development. Yearbook, 1962).

from elementary level to graduate school, regardless of the students socio-economical background as indicated below:

SELECTED CHOICES IN ORDER OR IMPORTANCE[5]

Popu-lations	A Suburb	B Urban Upward Bound	C Gifted	D University Lab School	E Graduate Students	F Sixth Grade
	2	2	4	2	4	2
	4	4	2	4	2	4
	3	3	1	1	1	1
	1	1	3	3	3	5
Low	5	5	5	5	5	3

GENERAL CATEGORIES OF TEACHING IMPORTANCE

1. Knowledge and organization of subject matter.
2. Adequacy of relations with students in class.
3. Adequacy of plans and procedures in class.
4. Enthusiasm in working with students.
5. Teaching methods.

Note that all of the groups sampled above whether from elementary, secondary, or the university level, chose items belonging to the category "Adequacy of relations with students in class" or "Enthusiasm in working with students" as being important for a teacher.

THE MULTIPLE-TALENT APPROACH

How is the teacher to help a person build himself? The first need is for the instructor to perceive well the individual. The classical view of a person was to think of him as being a reservoir of knowledge. The

[5]Modified from unpublished material provided by Rodger Bybee, Laboratory School, University of Northern Colorado, 1970. No title.

teacher's role was to fill the mind with information. Hence, the teacher who pumped information in and covered more subject matter was thought to be a good instructor. This is an obsolete view. Today the teacher must consider the "total person." He should have a wholistic and not a fractionated view of the individual. Guilford, Taylor, and others have shown that a person is a collection of over 120 talents.[6] The manifestation and development of these talents build the self-concept and contribute to mental health helping the person become a fully functioning individual.

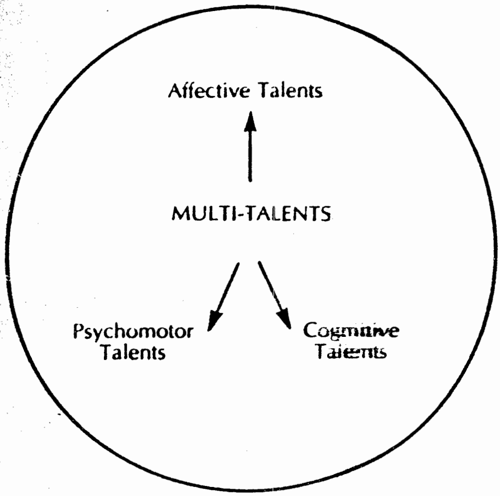


Figure 9 *Wholistic View of the Person*

Dr. Taylor states that since individuals are a collection of such talents—academic, creative, planning, organizing, social, forecasting, communicating, decision making, etc.—a multi-talent approach to teaching is required. By this he means that teachers should attempt to develop all the talents of his students rather than just the academic ones. To evaluate a student solely on the basis of academic talent is to insult him as a person.

To perceive students as possessing many talents broadens the vision of the teacher and insures better interaction between the teacher and the student. If students are viewed through a multiple-talent, perceptual framework, all of them are in some way above average. Dr. Taylor states:

[6]Calvin W. Taylor, "Multiple Talent Approach Teaching Scheme in Which Most Students Can Be Above Average," *The Instructor* (April 28, 1968): 27.

If we restrict ourself to cultivating only one talent, we will merely find the top 10 percent to be highly gifted, but if we will seek for the highly gifted in each of several different talents, the number found to be gifted will increase tremendously. In fact, if we cultivate three talents instead of only one, the percent found to be gifted will more than double (will be over 20 percent). Furthermore, if we work in six talent areas, the percent who are highly fitted will triple (will be about 30 percent).[7]

TAYLOR MULTI-TALENT APPROACH EVALUATIONAL CHART

	Academic Talents	Creative Talents	Communi-cation Talents	Planning Talents	Forecast-ing Talents | Decision-Making Talents	Other Types of Talents
Language Arts	X					
Social Studies	X					
Humanities	X					
Arts	X					
Biological Sciences	X					
Physical Sciences	X					
Mathematics	X					
Other Subjects	X					

Dr. Taylor further points out that for any one talent only 50 percent will be above average. However, if you combine talents to group students, using six talents, over 90 percent will be above average. Teachers have traditionally thought that academic talent correlated well with other talents. Taylor has shown this is not true. In fact, some of the most creative individuals may be the poorest academically. No longer can a

[7]Calvin Taylor, "Accent on Talent," *An NEA Service to the Schools of the Nation*, 2, No. 2 (January 1968).

teacher presume he's a good teacher if he just tries to develop academic ability.

What talents are being developed by these students?

Courtesy of Harold Pratt, Science Supervisor, Jefferson County, Colorado

The understanding of the complexity of developing all the human talents may be frightening. But, think for a moment of the beauty of the idea—no student is below average in all talents. Fifty percent of the students may be below average academically. However, if the outstanding talents of academically poor students are manifested, these students will experience feelings of success. This recognition will affect positively their self-concept and contribute to their expectancy level so that they will eventually believe "I can learn and be rewarded for my talents in school." As a result, their academic achievement will likely improve.

It seems reasonable, therefore, that a modern instructional theory should have at its foundation a dedication to build the self-concepts of students. The teacher should perceive the student in a wholistic manner as having over a hundred talents. The instructional process would be devised to maximize the manifestation of these. This means that the instruction would be student centered, investigative, and discovery oriented rather than teacher dominated. The instructor no longer does all the planning, organizing, decision making, etc., because to do so robs the students of the opportunities to develop these talents. With a self-concept—multi-talent—discovery approach, the teacher acts as a facilitator of learning by providing helpful guidance, rewarding all talents, and enjoying watching students grow into competent persons characterized by positive self-concepts and mental well being.

A MODERN INSTRUCTIONAL THEORY

BETTER MENTAL HEALTH
↑
Resulting in
↑
SELF-CONCEPT OF THE PERSON
↑
Builds the
↑
MULTI-TALENT DEVELOPMENT
↑
Contributes to
↑
LEARNING BY INQUIRY

SUMMARY

Every teacher as he interacts in the learning environment evolves a theory of instruction which he modifies throughout his career. The principles of educational psychology and sociology provide the sinews for the theory, and practical experience, the web. Jerome Bruner has stated an instructional theory has six characteristics: prescriptive, normative, motivating, structured, descriptive of effective sequence, and definitive of pacing rewards and punishments.

As has been suggested, fundamental to a modern science instructional theory is the belief in the need to help students in building their self-concepts. The achievement of this depends upon the instructor "reading well," perceiving the needs, inadequacies, and potential of his students. Important to this perception is the realization that each student is a composite of over 120 talents, i.e., academic, creative, com-

What talents are being developed by these students?

Courtesy of ESCP, Boulder, Colorado

munication, planning, forecasting, and decision making. Note, academic talent is only one of these. An instructor restricting his goals solely to the manifestations of academic talent limits the horizons of learning. The facilitation of multi-talent development should be the aim of every teacher. For, it is through the development of talents that the individual gains insights into his "person," builds his self-concept, achieves a feeling of identity, and gains a belief in his significance as an individual. If a teacher looks upon his class through a multi-talent vision, he sees every student as being above average in many respects. By interacting with students through this philosophical framework, he is more likely to respond in a positive manner, be more human, and be thought of by his students as a good instructor.

A teacher constantly has to work at improving his perceptual acuity of students. Where are their minds? Why are they having difficulty with a problem? What is wrong with their thinking processes? How can this be corrected? How can they improve their thinking facility? Fortunately, there is a wealth of research providing assistance to instructors in answering these questions. The next two chapters endeavor to provide a base for replies to these questions and assist you further in building a foundation for a modern instructional theory.

Further Investigation and Study

1. What is your present theory of instruction and how do you think you will modify it in the near future?
2. A dynamic teacher constantly modifies his theory of instruction. Why?
3. How do you feel about teaching to build self-concepts?
4. How will you go about building the self-concepts of your students?
5. What are Bruner's six characteristics of a teaching theory and what are their implications for you?
6. How would you design a learning situation to manifest multiple talents?
7. Describe what kind of teacher you hope to be five years from now.
8. What has the reading of this chapter done to your self-concept? Why?

3

Piaget's Theory of Cognitive Development

For over forty years Dr. Jean Piaget and his coworkers at the Genetic and Epistemology Institute in Geneva, Switzerland, have studied how the human mind develops. A baby clearly comes into the world with an unfinished mind and, as he grows and matures, he slowly evolves into a mature adult capable of performing fantastic computer-like operations. What is the sequence of mental development—how does the mind evolve from the babblings of a child to the creative intellectualizing of a fully functioning adult? Piaget believes individuals pass through four stages of mental development. They are:

Sensorimotor	0-2 years
Preoperational	2-7 years
Concrete Operational	7-11 years
Formal Operational	11-14 years

It would appear from these above stages that all high school students would perform mental tasks similar to adults after fourteen years. But it must be remembered that these stages refer to the majority of individuals and that there may be a considerable number of students in any one class who are not at the level indicated above. In fact, we have had experience in working with students in an inner-city high school where many of them did not perform well on formal operational tasks. If a science teacher tried to get these students to do assignments requiring mental operations at this level, he was doomed to failure before he started. It must be remembered, furthermore, that there are degrees of mastery of cognitive mental abilities; a person never ends his ability to use his mind more efficiently and effectively except perhaps in the waning years of life.

Most middle and high school science teachers will have students in their classes who have difficulty in thinking on the formal level. Teachers should therefore become aware of Piaget's theory, particularly concerning the concrete and formal levels, so they can recognize these difficulties and interact and respond more wisely to students.

A brief synopsis of each of the stages is listed below:

Sensorimotor Stage (0-2 years)
A period of discriminating and labeling

A. *Child stimulus bound.*

This sensorimotor stage is so named because during this stage the child interacts with the environment mainly using his senses and muscles and is directed by sensations from without. He develops his ability to perceive, touch, move, etc., at this time. Most of his body motions are, in a sense, an experiment with the environment. As the child interacts with his surroundings, he slowly learns to deal with it. For example, he eventually perceives depth whereas in the early part of the stage he only sees things as being flat.

B. *Order and organization begin.*

As a child develops he is faced with the challenge of taking information in and then organizing it so that later he will be able to call upon it as needed in his interactions with the environment. A child, therefore, obtains through encounters with his environment several kinds of experience. One kind of experience, perceiving the phenomena about him, is mainly *physical.* Another type of experience is mainly mental. When a child acts upon information in his mind, for example, he classifies it or files it away in an appropriate niche in the cerebral tissue. By so doing, he is obtaining mental experience; he is, in a sense, learning to program a computer—but this computer is his mind.

During the sensorimotor stage, the child is exposed to a wealth of experience. It is this experience that helps him develop the foundation of cognitive skill so important for the growth of the later stages of development. The better the experience of the child, the greater mentality he will have in the future. He begins to form in his mind rudiments of cognitive activity which are organized progressively into more elaborate schemes as he develops. He begins by adapting his innate reflexes to the objects around him and proceeds by coordinating the various actions that are possible on each object, thus learning the object's properties. He touches, feels, pushes, and slides the objects about him, learning, as a result, that they have certain properties. Later he may use these properties in solving practical problems. As he develops and uses his mind, he is finally able to recall mentally the properties of objects without having to test them each time he confronts them.

C. *The child doesn't perform any mental operations without doing them physically.*

The child in the sensorimotor stage has no imagination for objects or acts. What is not in his sight is not in his mind. He cannot add, subtract, or even classify unless he is acting on real objects. These thought processes only become meaningful to him in later stages of mental development. Even the most rudimentary sense of direction and purpose does not develop until the child is well into this stage. He is, for example, unable to detour or remove an obstacle without forgetting where he is going.

D. *Labeling ability develops.*

At the end of this period the child is able to imagine. He can call to mind certain people, animals, objects and activities. By age two, he has "names" for many things and activities enabling him to elaborate his concepts in the next stage. Space is limited to the area in which he acts, and time is limited to the duration of his actions. Progress develops as he becomes more involved with activities concerning space and time.

Preoperational Stage (2-7 Years)
The Intuitive Stage—Child Stimulus Limited

A. *Child Can't Do Operations*

The second stage of mental development (age 2-7) is preoperational. It is called preoperational because the child is *not* yet capable of carrying on any mental *operations*. Piaget's examples of mental operations include those listed in the following chart.

LOGICAL OPERATIONS

Adding	+	Combining
Subtracting	−	Taking Away
Multiplying	×	Repeating
Dividing	÷	Repeating Subtraction
Correspondence	∼	Aligning One Row With Another Row
Placing in Order	>	This Is Greater Than Or This Is Less Than
Substituting	=	Replacing Something Similar With Another Entity
Reversibility	⇄	Subclasses Belong to a Class — A Class Has Subclasses

During the preoperational period the child continues to perform many actions. Piaget believes the child must have many encounters with the environment in order to act on objects. The early actions he performs serve as the bases for the formation in later years of internal mental actions. In the preoperational period, actions become internalized. For example, the child thinks of moving an object (a mental action) before he moves it.

In addition to these operations, the preoperational child also is unable to perform certain infralogical operations. The word Infra in Greek means below. Infralogical operations then are considered by Piaget to be mental processes requiring a lesser degree of sophistication than formal operations. Most of the logical and infralogical operations are not demonstrated by the child until after the age of seven when he reaches the concrete operational level of mental development.

B. *Child stimulus limited.*

The child in this stage no longer operates just on stimuli from the environment. His mental images or representations, however, are limited

INFRALOGICAL OPERATIONS	
Observing	Looking at Something Critically
Measurement	How Long, High, What Volume, Etc.
Quantity	How Much
Time	Now, Future, Past
Classifying	Grouping According to Similarities
Space	Room, Home, Community, Country, Continent, World, Universe
Interpersonal Reactions	Getting Along with Others—Noting the Effects of One's Behavior on Others
Values	Establishing Values

to what he has experienced. He operates on a plane of representation, and he can use language. However, during this period the child may use the images he has formed in his mind incorrectly. He may in the early part of this stage, for example, call all men "Daddy." The preoperational stage is said to be intuitive because as the child develops he begins to sense mentally the difference between such things as individual item and its class, singular and plurals, some and many, man and men, and "Daddy" and other men.

C. *Centers, does not decenter attention.*

The preoperational child centers his attention usually on the surface of the problem. He may see only the superficial features that stimulate him the most. For example, if you take a ball of putty and roll it out, the child will notice that it is longer; he centers on length. However, he will not notice that the putty is also thinner; he has not decentered his attention to include width. If you ask him whether the rolled out putty weighs more, less, or the same as the ball of putty from which it was made, he will usually say the rolled out putty weighs more even though you may roll it back into the ball once again in front of him (Figure 10).

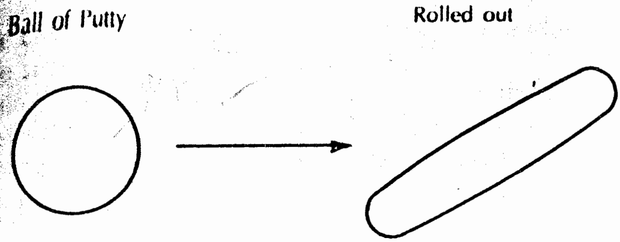


Figure 10 *Child Centers on Length and Thinks There is More*

D. *Focuses on states, not transformations.*

A preoperational child cannot combine a series of events to show how the changes they have undergone unify them. For example, a child is shown a series of pictures of a pencil falling and asked to order them in the manner the pencil fell; he can't do it. He focuses on the state of the pencil before and after it has fallen and will probably place the first and last picture in order but be confused about the others. He wouldn't, for example, be able to tell you when an apple would no longer be an apple as you chopped it up to make applesauce.

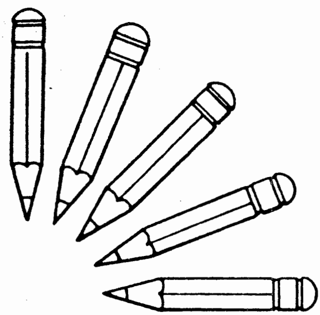


Figure 11 *Transformation*

E. *Thought processes not reversible:* A → B, but doesn't think of A ← B.

A child at this stage doesn't reverse his thought processes. If he is asked: "What is a chicken?" he will say, "It is a bird." Then, if asked: "What would happen if all the birds were killed? Would there be any chickens left?" he will probably reply, "Yes." If you force him into giving some other answer you will usually get an irrational one such as: "There are chickens left because they run away." The child doesn't realize that the subclass chicken belongs to the class bird. If the class is destroyed then the subclass is also destroyed. To grasp this point he would have to have a good idea of class and subclass plus be able to reverse his mental process to go from class to subclass as well as from subclass to class.

F. *Understanding change and probability absent.*

The understanding of change and probability is absent. Children in the preoperational stage have *difficulty* in forming genuine ideas of change and probability.

G. *Animistic, artificialistic explanations common.*

The child of this period is animistic and artificialistic in his view of the world. He may believe that anything that moves is alive. If you ask him how a crater was formed, he is likely to say that it was formed by a giant. He has names for all kinds of objects and thinks the name is inherently a part of the object and comes with it. All things have a purpose. The moon and sun move because they want to, etc. The "why" questions children in this stage constantly ask are an effort to find simple purpose.

H. *Play and reality confused.*

The preoperational child cannot discriminate play from reality. This is due to the fact that he hasn't developed sufficient rational structure because most of his beliefs are relatively arbitrary and have not been derived from reason.

I. *Egocentric.*

It is difficult for a child of this period to understand views other than his own. For example, he talks while paying little attention to whether he is being understood or even listened to. He thinks the way he sees things is the way all people view them. This egocentricity changes in time largely by being confronted in social interaction with other individuals' various opinions.

J. *Time and space concept now expanded.*

His impression of time has changed during this stage from thinking only in the immediate present to being able to think of future and past time. His understanding of time, however, doesn't extend very far beyond the present. Space has enlarged to include an understanding of his house and neighborhood.

Concrete Operational Stage (7-11 years)
The Child is Able to Perform Operations

A. *Thoughts stimulus related.*

During the concrete operational stage a child slowly becomes proficient in developing his ability to perform all of the logical and infralogical operations listed above. Thought is mainly limited to thinking about things, not mental propositions. However these students can be stimulated by a book or other aid to think of places and times with which they have had no experience.

B. *Class, relation concepts devised.*

One of the main outcomes of this stage of development is that the student constructs class and relation concepts which enable him to more effectively order what he encounters in his environment. He conceptually organizes his environment into cognitive structures—ideas. Each new encounter with nature does not require extensive examination but can be classified according to structure and function, thus allowing for more efficient responses. The child can go beyond things and think of groups. Since the concrete operational person can do reversible thinking, he is able, late in the stage, to classify things in an ascending as well as descending manner. He realizes ducks are birds—ascending—and if birds are destroyed there will be no ducks. He therefore reverses his thinking and in this case descends from birds to ducks in his thought processes. This ability to form classes and groups enables the child to expand his mental activity greatly.

ASCENDING AND DESCENDING HIERARCHY

Ascending

ducks are birds

Descending

birds killed — no ducks > Reversible thought

C. *Limited hypotheses possible.*

A child of this period can think of what happens when the volume of a container is altered; that is, what happens to a container receiving liquid as well as to one being depleted of it. However, he is usually limited to making only one hypothesis involving only one variable, and he is better able to do this if he sees the containers before him. It is difficult for him to act mentally upon the problem and determine an answer.

D. *Understanding of space and time greatly expanded.*

The concrete operational child understands some notions of geographical space and historical time.

E. *Action representation occurs.*

The child of this period mentally represents action. Mental action takes the place of performing some real act on an object. For example, if you add water from a wide flat jar to a slender jar, the water level in the slender jar will be higher. The concrete operational child, when asked if there is more or less water in the slender jar than in the wide jar, will reply, unlike the preoperational child, that it is the same. If you ask the concrete operational child why he thinks this is true, he will probably reply, "If you returned the water to the wide jar, you will have the same volume as before." He performs mentally the action of refilling the wide jar with water. This mental activity substitutes for the actual replacing of the water in order to come to the same conclusion. Dr. Elkind, a specialist on Piaget, has said that this is similar to a child doing math in his head instead of counting on his fingers.

Formal Operational Stage (12-15 years)
Development of Abstract Reflexive Thinking

This is the stage which the majority of students should attain in early high school. However, in most classes there probably will be some individuals who still respond to tasks in concrete ways.

A. *Child stimulus-free.*

The student is stimulus free in that he doesn't need an external stimulus to set up the thinking process. In this sense, he is free from immediate stimulation in directing his behavior. He can originate many of his own ideas. As a result, his possibility for creative enterprise is broadened.

B. *Reflexive thinking processes begin.*

One of the main characteristics of this stage is the student's ability to do reflexive thinking. The student in this period begins to think like an adult. He is able to think back on a series of mental operations— reflect on them. In other words, he can think about his thinking. He also can represent his own mental operations by symbols. In science, for example, a student can be asked after finishing an experiment if he were going to do it again how he would improve it. The student would have to reflect and evaluate everything he had done in order to come up with an improved approach. When an instructor first demands such reflexive thinking, he may encounter some difficulty because students previously have not used their minds for this purpose. With some teacher guidance, however, they soon progress in being more reflexive.

C. *Probability becomes understandable.*

The formal operational student thinks in terms of many possibilities rather than being limited to the facts before him. He can think of ideals as opposed to realities.

D. *Thinking processes more hypothetical—deductive.*

He formulates hypotheses as testable ideas in his mind and does not necessarily think of them as realities. He is more likely to demonstrate deductive patterns of thought than at previous stages of mental development. Teachers, therefore, should give him many opportunities to make hypotheses so that he develops this ability to a high level.

E. *Abstraction processes more developed.*

The child of this period is more at ease with mathematical abstraction and manipulation. Dr. Flavel says:

> In brief, the adolescent can deal effectively not only with the reality before him...but also the world of pure possibility, the world of abstract, propositional statements, the world of "as if." This kind of cognition is adult thought in the sense that these are the structures within which adults operate when they are at their cognitive best, i.e., when they are thinking logically and abstractly.[1]

The above summary of the intellectual development of children is admittedly very brief, but it should give you a viewpoint that will be of considerable assistance in teaching science. Interest in the cognitive development of children has been accelerating among psychologists,

[1]John H. Flavel, *The Developmental Psychology of Jean Piaget* (Princeton, N. J.: D. Van Nostrand Company, 1963), pp. 86-87.

scientists, and science educators over the last decade. As a consequence, many modern science curriculum projects have been designed to give greater attention to the child's cognitive developments. This has been particularly so on the elementary levels. Some projects on the elementary level are The Illinois Studies in Inquiry Training, The Science Curriculum Improvement Study at the University of California, the Elementary Science Study, the Madison Project, and Science, A Process Approach, plus many others in science and mathematics. The middle and secondary school curriculum revisions have been related to Piaget's work in that they stress critical thinking through learning. The science subject matter is used, therefore, to enhance cognitive development.

A word of caution with respect to the age grouping of the model of child development presented in the previous pages: the age periods marking cognitive development should be used only as a guide. Individuals vary considerably. Many individuals in junior high and senior high are in a state of transition between concrete and formal operations. This means they behave as concrete thinkers on some activities but respond formally on others. Furthermore, Piaget's work comes from research studies of children as they are and not as they might be. If enriched and well-designed experiences are provided, the chronological age at which these different steps develop might presumably vary while the sequence would undoubtedly remain the same.

There is a question among curriculum developers as to whether or not the cognitive development of the child can be accelerated. Whether it can or not does not seem as important as providing experiences for developing good rational thinking at each of the cognitive stages. Piaget believes it is most important to involve students in rich experiences at their level of development because to do this is more likely to provide a better foundation for later stages of cognitive growth. He concentrates on the quality of experiences at each level.

The paramount concern of teachers, therefore, should be the designing of experiences to insure that students have opportunities to perform desirable mental operations at their stage of development. For example, if students are to operate more scientifically as adults, they must have opportunities to behave scientifically in all of the many ramifications the word implies, and they must have these opportunities throughout their school lives. An awareness of the cognitive development of the child and a translation of this awareness into teaching practices, especially in science teaching, provides a great challenge. The meeting of this challenge can make the difference between teaching as a professional or a technician.

In what Piagetian level of cognitive thinking are these students involved?

Courtesy of Harold Pratt, Science Supervisor, Jefferson County, Colorado

SUMMARY OF THE CHARACTERISTICS OF PIAGET'S STAGES OF MENTAL DEVELOPMENT

SENSORIMOTOR Birth - 2

1. Mainly directed by stimuli—outside the mind
2. Preverbal—no language
3. Thought proceeds from actions
4. Learns to perceive and identify objects
5. By end of period distinguishes parents, animals, and knows names
6. Rudimentary sense of direction and purpose appears late in stage
7. Time—present
8. Space—immediate

PREOPERATIONAL 2-7

1. Can't perform operations but language develops
2. Can't do abstract thinking
3. Egocentric
4. Nonreversible thinking

5. Mainly acts on perceptive impulses
6. Static thinker—doesn't think of series of operations
7. Time—thinks of present, future, past but limited to short duration
8. Space—house, yard, neighborhood

CONCRETE OPERATIONAL 7-11

1. Performs operations: combining, separating, ordering, seriating, multiplying or repeating, dividing, substituting, *reversible* thinking; can do correspondence by end of period, analyzes, aware of variables, classifies, measures

FORMAL OPERATIONAL 11-15

1. Performs hypothetical and propositional thought
2. Reflexive thinker—evaluates his thinking processes
3. Synthesizes
4. Imagines
5. Does abstract, nonconcrete conceptual thinking
6. Understands probability
7. Questions ethics
8. Does ratios, proportions, and combinatorial logic

IMPLICATIONS OF PIAGET'S THEORY FOR SCIENCE TEACHING

The following are some suggestions to follow in applying what you have learned about cognitive development to the teaching of science.

1. Attempt to determine which students in your class are concrete or formal in their thinking. This can be done by asking students on an individual basis to hypothesize about some scientific problem which is not visible to them, to do reflexive thinking, i.e., ask if you were going to do an experiment again how would you do it better? Give an Invitation to Inquiry: (See Chapter 7 for examples of these) present some problem a scientist was concerned with and ask them how they would go about solving it. If students do not do well on these tasks, it is indicative that they are concrete operational or in a state of transition from one stage to another. This would indicate that the teaching should rely less on verbal instruction and more on performing actions with materials and being more involved with laboratory or pictorial learning than reading.

2. If students are in the formal, operational stage, require them often to analyze their procedures, data, etc., and suggest ways of improving the experimental design. These same activities may be carried on in class discussion. The students in cognitive transition may be able to do some of these activities, while those who are formal in their thinking should experience little difficulty.

3. Ask students to design an investigation. Rather than telling them at first how to perform some experiment, ask students how they would set up an experiment to find the answer to the problem under discussion. (See the guided prelaboratory question section of the discovery lessons in Chapter 4 to see how this is done.)

4. Formal operational students begin to develop the ability to establish criteria for classification. Provide students with a number of things and let them establish a classificational scheme.

5. Give students as much freedom as they can handle in creating, inquiring, and discovering. This allows for more cognitive involvement contributing to their thinking ability.

6. Involve students in group projects requiring the solving of problems, e.g., pollution. Try to constitute the groups so that there will be opposing views requiring interchange of ideas. Piaget believes that social interaction is one of the main factors forcing cognitive growth. Certainly an intellectual argument can provide food for thought.

7. The adolescent mind becomes relatively capable of determining and synthesizing general properties. Adolescents, therefore, should have many opportunities to use their minds to discover general laws and principles of science.

8. Formal students are able to make correlations and deal with proportionality. A teacher should be aware and tolerant of this fact. He should provide the necessary guidance to help students comprehend problems of this nature. Many students, however, may have considerable difficulty in accommodating these ideas until they have had wide experiences with them.

9. Students should be encouraged to make hypotheses and do propositional thought, evaluate data, and originate their own problems. Ask as often as possible throughout your instruction the following questions:

a. What hypotheses would you make?

b. If you were going to do an experiment to find out, what would you do?

c. If you were going to repeat the experiment, how would you do it better?
d. What other problems or experiments do you suggest?
e. What are all the ways these results could be affected positively or negatively?
f. What combinations of factors would give the best results?

Above all, allow students as many opportunities as possible to think and use their minds. They may do this by organizing how they are going to perform a task, motivating other students to work with them on a project, interacting with other students about a problem, collecting and interpreting data, deciding on some class presentation they are going to give, creating something for the class, etc.

10. Do not discriminate against students because of their operational level. Remember your function is to help students become operationally more sophisticated. To demean a student because he is concrete in his thinking may inhibit him from striving to become formal. If a lack of formal thinking makes it appear that a student is not very smart, steer away from problems where formal reasoning is required. How many students refuse to even think or reason out an answer to a complex problem. They just guess and if the answer is correct that is great but if it isn't they can't be bothered.

The fact that some students are not formalistic probably acts as a discriminating influence against them in taking certain courses. Two doctoral students at the University of Northern Colorado, Ball and Sayre found only one physics student out of fifty-seven interviewed was nonformalistic and he was in serious scholastic difficulty. Students undoubtedly get the "word" that physics is difficult and that they can't do it. Many, therefore, do not enroll in the course. This is particularly depressing since physics if taught by an understanding instructor aware of Piaget's theory could be instrumental in helping these students become formalistic.

It is of interest to note that physics enrollments have been declining for a number of years. If this situation is to be changed, it seems reasonable that either a massive effort is needed to insure better operational achievement of students prior to the time they take physics or the instruction and evaluation in the course must not be based so heavily on formalistic reasoning. If this is done, it is reasonable to expect students to more likely think they could be successful in the course, thereby causing increased enrollments.

COMPARISON OF JUNIOR HIGH SCHOOL STUDENTS' GRADES WITH THEIR OVERALL PERFORMANCE ON THE PIAGETIAN TASK INSTRUMENT*

Scholastic Grade	No. of Students Receiving	Formal Performance	Nonformal Performance	Percent Formal	Percent Nonformal
A	19	8	11	42.1	57.4
B	74	13	61	17.6	82.4
C	78	1	77	1.3	98.7
D-F	43	1	42	2.3	97.7

COMPARISON OF SENIOR HIGH SCHOOL STUDENTS' GRADES WITH THEIR OVERALL PERFORMANCE ON THE PIAGETIAN TASK INSTRUMENT

Scholastic Grade	No. of Students Receiving	Formal Performance	Nonformal Performance	Percent Formal	Percent Nonformal
A	51	45	6	88.2	11.8
B	78	49	29	62.8	37.2
C	55	20	35	36.4	63.6
D-F	21	4	17	19.0	81.0

SUMMARY

Piaget has researched for over forty years on how the minds of children develop. He says individuals pass through four stages of cognitive development as they mature. These are sensorimotor, 0-2 years; preoperational, 2-7 years; concrete operational, 7-11 years; and formal operational, 11-15 years.

Piaget's work centers upon an individual being able to perform operations. Operations include such mental processes as adding, subtracting, multiplying, dividing, performing correspondence, ordering, substituting, and reversing. Individuals slowly develop these rational skills; consequently, sensorimotor and preoperational students are unable to perform them while in the concrete operational period. Formal operational students, in addition to these operations, can perform

*Daniel W. Ball and Steve A. Sayre, "Relationships Between Student Piagetian Cognitive Development and Achievement in Science" (unpublished Ph.D. dissertation, University of Northern Colorado, Spring 1972).

hypothetical-deductive thinking, or propositional reasoning, and do reflexive thinking.

Although the ages given for the periods above indicate that by high school individuals should be formal operational, in fact, many are not. Frequently, in middle and secondary schools instructors have, within the same class, individuals at varying mental stages many of whom are in transition from one period to another. Teachers should adjust their teaching accordingly. For example, concrete operational students do not perform well verbally. Teachers should, therefore, provide experiences where they can learn more effectively by being involved in laboratory or pictorial types of activities.

Further Investigation and Study

1. Take the following Self-Evaluation Inventory to see how well you have learned the information contained in this chapter compared to other students in the class.

HOW WELL HAVE YOU LEARNED THE MATERIAL OF THIS CHAPTER?

Directions: Listed below are some objectives relative to Piaget's theory. Read each and answer the questions posed. Then rate each objective as to content and interest, indicating what you knew about and your interest in it before studying this area and your knowledge and interest now after finishing this portion of your study. Circle the appropriate number and mark B for Before and E for End next to the number as indicated below.

Example: OBJECTIVE	STUDENT EVALUATION *Low Moderate High*
1. Distinguish important Piaget mental operations	Content (1)B 2 3 (4)E 5 6 Interest 1 (2)B 3 (4)E 5 6
OBJECTIVES	**STUDENT EVALUATION** *Low Moderate High*
1. State the four stages of Piaget's developmental theory.	Content 1 2 3 4 5 6 Interest 1 2 3 4 5 6
2. Identify three characteristics of each of the stages.	Content 1 2 3 4 5 6 Interest 1 2 3 4 5 6
3. Give two ways of identifying concrete and formal operational thinking.	Content 1 2 3 4 5 6 Interest 1 2 3 4 5 6
4. State four specific ways to ask questions that will help students develop cognitively in science.	Content 1 2 3 4 5 6 Interest 1 2 3 4 5 6
5. Define a. Logical operations	Content 1 2 3 4 5 6 Interest 1 2 3 4 5 6

OBJECTIVES	STUDENT EVALUATION
b. Transformation	Content 1 2 3 4 5 6 Interest 1 2 3 4 5 6
c. Reversible	Content 1 2 3 4 5 6 Interest 1 2 3 4 5 6
d. Egocentric	Content 1 2 3 4 5 6 Interest 1 2 3 4 5 6
e. Establishing a class hierarchy	Content 1 2 3 4 5 6 Interest 1 2 3 4 5 6
f. Propositional thought	Content 1 2 3 4 5 6 Interest 1 2 3 4 5 6
g. Reflexive thought	Content 1 2 3 4 5 6 Interest 1 2 3 4 5 6
h. Cognitive development	Content 1 2 3 4 5 6 Interest 1 2 3 4 5 6
6. List five types of operations	Content 1 2 3 4 5 6 Interest 1 2 3 4 5 6
7. Name five educational implications of Piaget's theory.	Content 1 2 3 4 5 6 Interest 1 2 3 4 5 6
8. Give a reason, suggested by this chapter, for having students learn by inquiry.	Content 1 2 3 4 5 6 Interest 1 2 3 4 5 6
9. State whether reading this chapter has been valuable and has helped alter the way you shall look at students.	Content 1 2 3 4 5 6 Interest 1 2 3 4 5 6
10. Indicate whether you would like to learn more about Piaget's work.	Content 1 2 3 4 5 6 Interest 1 2 3 4 5 6

After having completed the above, compare your results with another student in the class. Discuss with him any significant variations between your two evaluations.

2. Read: David Elkind, "Children and Adolescents, Interpretive Essays of Jean Piaget," Oxford University Press, 1970, and devise some simple tests to determine the mental thinking of students in a class.

3. List five things that had the greatest impact for you in this chapter.
4. What do you think about the use of the above self-evaluational inventory to determine how well you learned the material?

*Of only one thing I am convinced. I have never seen anybody improve in the art and technique of inquiry by any means other than engaging in inquiry.**

4

Discovery and Inquiry Instruction

Over the last ten years, all of the programs for developing modern, innovative science instruction for the elementary and secondary schools funded by the United States Government National Science Foundation have been discovery or inquiry oriented. Millions of dollars have gone into making science materials more relevant according to what is known about how students learn and the nature of science. In the history of man no greater expenditure of money has been devoted for an educational end.

INQUIRY AND DISCOVERY TEACHING IS NOT NEW

Although there has been this recent emphasis on discovery and inquiry teaching, such teaching is by no means new to education. Many excellent teachers for generations have used this approach. The one-room school houses that dotted landscapes in the early history of our country often had children involved in discovery activities.

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*Jerome Bruner, *Harvard Educational Review* 31 (Winter 1961): 32.

What is discovery or inquiry? Many educators use these terms interchangeably while others prefer to differentiate their meanings. In this book we use the terms differently. To us, discovery occurs when an individual is involved mainly in using his mental processes to mediate (discover) some concept or principle. For example: the student may discover what a cell is, i.e., form a concept of a cell, or later on he may discover a scientific principle: cells only come from cells. A discovery activity is a lesson designed in such a way that a student, through his own mental processes, discovers concepts and principles.

Concepts
1) cell 2) momentum 3) nucleus 4) solute
Principles
1) The environment affects living things. 2) Sound is produced by vibrating matter. 3) Evolution takes enormous amounts of time for its operation

For a student to make discoveries he has to perform certain mental processes such as observing, classifying, measuring, predicting, describing, inferring, etc. Modern elementary school science curriculum project materials are mainly designed to involve children in discovery activities.

Discovery —	The mental process of assimilating concepts and principles in the mind.
Discovery Cognitive Processes —	Observing, classifying, measuring, predicting, describing, inferring.

Starting in the middle school and becoming increasingly more sophisticated as students progress through the high school, materials are designed to stress inquiry. Inquiry teaching, however, is built on discovery, because a student must use his discovery capabilities plus many more. In true inquiry the individual acts as a mature scientist. An experimental scientist behaves in a number of ways in order to unravel the hidden relationships of nature. He performs certain relatively sophisticated mental processes, as indicated in the chart below:

INQUIRY
Asking insightful questions about natural phenomena
Formulating problems
Formulating hypotheses
Designing investigative approaches including experiments
Carrying out experiments
Synthesizing knowledge
Having certain scientific attitudes:
Objective
Curious
Open-minded
Desires and respects theoretical models
Responsible

The elementary child may observe mealworms and discover they are photosensitive to light. A secondary student may be asked to choose and investigate an organism and report research he has done on it. If he originates his own problem, designs experiments, and collects data, etc., he is behaving in an inquiry manner. Refer to the above charts on Discovery and Inquiry. How do their processes differ? How would you design a discovery-oriented lesson? How would you design an inquiry lesson?

Because secondary teachers often do not have a clear distinction in their minds between discovery and inquiry, they tend to overemphasize discovery activities. Remember, as Piaget indicates, adolescents are in the process of developing formal thought. They should, therefore, have opportunities to use this type of thinking. Hypothetical-deductive and reflexive thinking are two characteristics of this period. Formulating hypotheses, designing experiments, evaluating data, and looking back over an experiment to determine how it can be improved (reflecting) require these mental operations. Middle and secondary instruction should not only include discovery, but an increasing number of inquiry activities.

Clearly, one develops his discovery and inquiry abilities only by being involved in activities requiring the performance of the above types of mental tasks. Since an individual never really masters any of these in the complete sense, there is only a degree to which one becomes proficient in learning how to discover and inquire. Even the most sophisticated Nobel Prize scientist is still moving forward in developing his skills of investigating the phenomena of the universe.

The task of the school system is to construct its curriculum so students manifest their human investigative potential. Although many of the mental processes outlined above are not unique to science, they certainly should be stressed in science. In order to involve students in inquiry development an instructor might ask, for example: "Here is a roller skate. What should be done to it to make it move across a distance at a faster rate assuming we apply the same initial force to it each time?" What the instructor is doing in a cognitive sense is asking students to formulate hypotheses about how the skate could be moved. The students in responding act as scientists. They formulate hypotheses, and the more they perform such a mental process, the better they become at it.

WHAT ARE THE ADVANTAGES OF DISCOVERY AND INQUIRY TEACHING?

Already you are probably beginning to see some of the reasons discovery and inquiry teaching are permeating learning in the schools. Jerome Bruner, an eminent Harvard University psychology professor, has been instrumental in leading the movement toward discovery teaching. He has outlined four reasons for using this approach, as indicated in the chart below:

BRUNER'S REASON FOR DISCOVERY
1. Intellectual Potency
2. Intrinsic and Extrinsic Motives
3. Learning the Heuristics of Discovery
4. Conservation of Memory

By intellectual potency Bruner means an individual only learns and develops his mind by using it to think. In his second point he believes that, as a consequence of succeeding at discovery, the student receives a satisfying intellectual thrill—an intrinsic reward. Teachers often give extrinsic rewards (A's for example), but if they want students to enjoy learning, they have to devise instructional systems which will help students obtain intrinsic satisfaction. In Bruner's third point, he emphasizes that the only way a person learns the techniques of making discoveries is to have opportunities to discover. Through discovering a student slowly learns how to organize and carry out investigations. Bruner argues in his fourth point that one of the greatest "Pay-Offs" of the discovery approach is that it aids in better memory retention. Think for a moment of something you have thought out yourself and compare it with information you were told in a freshman science course. The material you reasoned out probably is still fresh in your mind even though you may have learned it years ago. On the other hand, concepts you were told in biology, chemistry, or physics often escape recall.

Although Bruner's four points are justifications for discovery teaching, they also have relevance for inquiry. This is so because the teaching strategies for the two approaches are similar in that they stress the importance of the students' using their cognitive mental processes to work out meanings of things they encounter in their environment.

Although Bruner has suggested the salient justifications for modern teaching, there are additional reasons for using student investigative approaches. Some of these are now listed.

1. *Instruction Becomes Student Centered.* One of the basic psychological principles of learning states: The greater student involvement, the greater the learning.[1] Usually when teachers think about learning, they have in mind that the student is assimilating some information. This is a very limited view of learning as was pointed out in Chapter 2. Learning involves those total aspects that contribute to the individual becoming a fully functioning person. For example, in inquiry situations students learn not only concepts and principles, but self-direction, responsibility, social communication, etc. In teacher-centered instruction, on the other hand, much of the opportunities for developing these talents are denied to students by the instructor. He or she provides the self-direction, retains the responsibility, etc. If you look at instruction as enabling a person to become more than he is in all the facets that make up a human, it is difficult to justify a teacher-centered learning environment.

2. *Inquiry Learning Builds the Self-Concept of the Student.* Each of us has a self-concept. If our self-concept is good we feel psychologically secure, are open to new experiences, willing to take chances and explore, tolerate minor failures relatively well, are more creative, generally have good mental health, and eventually become fully functioning individuals. Part of the task of becoming a better person is to build our self-concepts. We can only do this by *being involved* because through involvement we manifest our potential and gain insights into "self." Inquiry teaching

[1]Watson, Goodwin, "What Psychology Can We Feel Sure About?" *Education Digest* (May 1960): 19.

provides opportunities for greater involvement, thereby giving students more chances to gain insights and better develop their self-concepts.

How are these students building their self-concepts?

Courtesy of Harold Pratt, Science Supervisor, Jefferson County, Colorado

3. *Expectancy Level Increase.* Part of a person's self-concept is his expectancy level. This means that the student believes or expects he is able to accomplish a task on his own. He has learned from previous discovery and inquiry experiences that he can "think autonomously." In other words, from having had many successful experiences in using his investigative talents he has learned "I can solve a problem on my own without the help of teacher, parent, or anyone else."

4. *Inquiry Learning Develops Talents.* As mentioned previously humans are a collection of more than 120 talents; academic talent is only one of these. The more freedom a person has, the more opportunities he has to develop other talents such as creative, social, organizing, etc.

5. *Inquiry Methods Avoid Learning only at the Verbal Level.* Some years ago we saw Dr. Richard Salinger, a renowned science educator, play a game with some prospective Peace Corps science teachers to show them how easy it is for an instructor to mistake verbal play for real learning. He placed the following on the board:

Arks	>	Gorks
Gorks	>	Grons
Grons	>	Smoes

He then asked the students in rapid sequence: "What is an Ark to a Gork? What's a Gork to a Smoe? A Smoe to an Ark? An Ark to a Gron?" etc. The students soon became facile at playing the game. Dr. Salinger then erased the board and continued the game, although the students had difficulty, they could still play it relatively well.

Dr. Salinger then stopped and asked, "Haven't I taught you something? Haven't you learned something?" The students looked perplexed. Dr. Salinger said, "Come on, don't you know an Ark is greater than a Smoe? Couldn't I give you a test: An Ark is greater than ______? and couldn't you complete the test?" He then asked, "How often do teachers play Ark games?"

When you learned such definitions as osmosis, photosynthesis, ionic bonding, momentum, etc., did you play Ark and Gork games, or did you work out the meaning in your mind and really understand what you were learning? Inquiry teaching, since it stresses the student discovering for himself the meaning of his natural environment, tends to avoid "Ark and Gork teaching."

6. *Inquiry Learning Permits Time for Students to Mentally Assimilate and Accommodate Information.* Teachers often rush learning, resulting in students playing Ark games. Students need time to think and use their minds to reason out and gain insights into the concepts, principles, and investigative techniques they are involved in. It takes time for such information to become a part of the mind in a meaningful way. Piaget believes there is no true learning unless the student mentally acts upon information and in the process assimilates or accommodates what he encounters in his environment. Unless this occurs, the teacher and student are involved only in pseudo-learning (i.e., Arking), the retention of which soon fades into useless oblivion.

GUIDED VERSUS FREE INQUIRY

How much structure should be provided in inquiry situations? There should be enough to insure that the student has success in coming to understand some phenomenon in his environment.

We believe if students have not had experience in learning through inquiry, their lessons should be considerably structured at first. After they have gained some experience in carrying out an investigation, the structure should be lessened. We use a general term "investigative" to include both discovery and inquiry teaching approaches. The term guided discovery and inquiry is used where there is considerable structure given, and free discovery and inquiry indicates there is little guidance provided by the instructor. Shown on page 69 is an example of part of a guided inquiry lesson. Note that much of the planning is outlined by the teacher.

How do these students demonstrate modern teaching trends?

Courtesy of Bob Waters, University of Northern Colorado

HOW LONG CAN YOU BOIL WATER IN A PAPER CUP?

Junior High Level

Teachers note: Sections I through III are for the teacher only and Sections IV and V are to be duplicated for the student.

I. *Concepts*

A flame is a source of radiant heat.

Water, when heated, expands and gives off water vapors.

Water can absorb a considerable amount of heat.

Before a substance will burn, its kindling temperature must be reached.

The kindling temperature is the temperature at which a substance will first start to burn.

II. *Materials*

Nonwaxed paper cup
Bunsen burner, propane torch, or alcohol burner
Ringstand
Ring clamp
Wire Screen

III. *Prelaboratory Discussion*

Processes:

Hypothesizing	1. What do you think will happen to a paper cup when you try to boil water in it?
Hypothesizing	2. What do you think will happen first, the water boiling or the cup burning?
Hypothesizing	3. How do you think you could get a paper cup containing water to burn?
Designing an Investigation	4. What should you do to find out?

IV. *Pupil Discovery Activity*

Processes

Collecting Material	1. Obtain the following equipment: A nonwaxed paper cup, torch or burner, ringstand, ring clamp and screen.

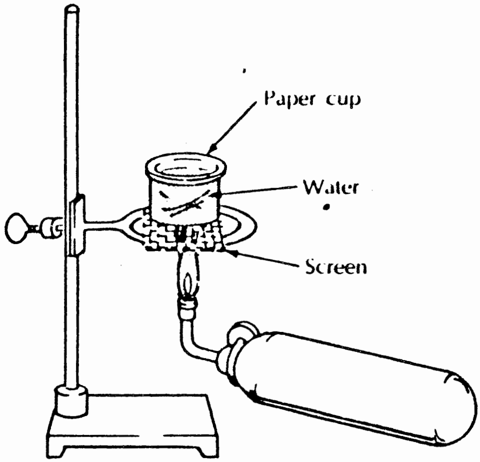

Figure 12

Designing an Investigation — 2. What ways could you use this equipment to find out if you can boil water in a paper cup?

Teachers note: The students should place the paper cup, containing not more than 5 cc. of water, on the wire screen as indicated in the diagram and heat it from below with the burner.

Following Directions — 3. If you can think of no other ways to test your hypothesis, set up the equipment as indicated by a diagram your teacher has.

Observing — 4. What happens when you try to heat the water in the cup?

Inferring — 5. What do you think the ring clamp and screen do to the heat from the flame?

Inferring — 6. What can you say about the heat energy entering and leaving the water as you try to heat it to the boiling point?

Inferring — 7. Why does the water level in the cup change?

Inferring — 8. What effect does water in the cup have on its temperature as it is being heated?

Inferring — 9. Keep heating the cup until all the water is evaporated. Record your observations and conclusions.

V. *Open-Ended Questions*

Processes

Hypothesizing — 1. If you took paper, cloth, wood, and charcoal and heated them, in what order would they start to burn? Why?

Criticizing	2.	If you were going to repeat the above experiment, what would you do to obtain better data?
Hypothesizing	3.	How would the results of the above experiment differ if you used a styrofoam cup?
Hypothesizing	4.	How would varying the amount of heat energy applied to the cup change the results?
Hypothesizing	5.	How would the results vary if there were a different liquid in the cup such as a cola, syrup, etc.?
Hypothesizing	6.	In what way would the results vary if the cup were supported by the top instead of being supported by a ring clamp and screen?
Designing an Investigation	7.	What other experiments does this above investigation suggest to you?

FREE INQUIRY

Complete free inquiry occurs when students originate and carry out their own investigations. Evidence from the "Free Schools," various summer programs for gifted students offered at many universities, and science fairs indicates that students can carry on this type of learning when given a chance and a limited amount of guidance. A modified free inquiry situation has also worked for many instructors. This differs from the totally free investigative approach in one important aspect and that is the instructor provides the problem. For example, teachers might provide the following situations.

Modified Free Inquiry

1. Here are some snails. Find out as much as possible about them.
2. Here is a pond and some apparatus. Find out as much as possible about how this pond changes over a year.
3. Here is some apparatus for studying motion. Set these up in any way you choose to study the movement of an object.
4. Here is some apparatus for studying circuits. Do what is necessary to find out as much as possible about circuits.
5. With this salt, do what ever you want to determine its physical and chemical properties.
6. Study clouds to determine any relationships between their formation and the type of weather that follows.

7. What should be done to improve the ecology of the school environment?
8. Here is some water that is supposed to be polluted. How well can you prove that it is?

Students using a quadrant in studying BSCS Biology.

Courtesy of Bob Waters, University of Northern Colorado

In the modified plan students are encouraged to attack the above problems on their own or in groups. The teacher is available as a resource person giving only enough aid as required to insure that the students do not become too frustrated or experience too much failure. The assistance the teacher gives, however, should be in the form of questions he asks that help students think about possible investigative procedures. It's always better to ask students questions giving them direction than to tell them what to do. For example, in the problem where the students are studying the pond, they may not think of studying population changes of organisms in the water. The instructor might, if the situation warrants, ask, "What do you think about how the population of organisms might vary during the year? What would you do to find out if it does?" This question given at the right time may provide just the needed stimulus to cause the students to explode with creative investigative ideas. Contrast this with a teacher who says, "Study the population changes of organisms to find out how algae and invertebrate organisms vary with the time of year." In the second instance the teacher has robbed the students of many opportunities for thought and creativeness.

After students have studied and learned many of the processes of science and performed modified free inquiry tasks, the instructor might ask some of the following as a basis for determining class activities.

1. What do you think is the most important problem in our community?
2. Now that you have studied salts, algae, light, heat, radiation, animal behaviors, etc., what problems can you come up with that you would like to investigate individually or in teams?
3. Now that you have finished this experiment (for example, in population), what other experiments can you think of and which of them would you like to do?
4. When you see problems in the community (pollution, etc.) or some problem comes to you related to science that you would like to discuss, bring it to our attention in class.

What kind of thinking are these students doing with the ESCP materials?
Courtesy of Bob Waters, University of Northern Colorado

Not Everything Can or Should Be Taught by Inquiry

Although inquiry teaching should receive a major emphasis in science teaching, not everything can or should be taught by inquiry. For example, for students to learn the names of chemical compounds, they just have to memorize them. If you want students to learn how to handle and use a microscope you will probably have to show them. If there are safety precautions to be aware of, the instructor must tell students about them.

You, as a teacher will have to establish a value system and use it as a guide in determining when you will or will not teach something by inquiry. The preceding section should give you some assistance in evolving your philosophy in this respect.

What Does The Present Research Say about Using Investigative Teaching Approaches?

Although the research findings are still in need of further investigation, particularly concerning how students vary in feelings about the different approaches (affectivity) and the development of more than just subject matter achievement differences (multi-talents, self-concept, etc.), they do indicate that the investigative approaches have been successful. Dr. Shulman, as a result of a Conference on Learning by Discovery summarizes the research in discovery as follows:

> In the published studies, guided discovery treatments generally have done well both at the level of immediate learning and later transfer.[2]

Similar conclusions have been found by the Biological Sciences Curriculum Study for inquiry approaches in biology,[3] by William Day[4] and Omar T. Henkel for physics,[5] by John Montean for general chemistry and general science,[6] plus many more. Carl Rogers has written the popu-

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[2]Lee S. Shulman, "Psychological Controversies in the Teaching of Science and Mathematics," *Science Teacher* (September 1968): 90.

[3]"Evaluation," *BSCS Newsletter* No. 24 (January 1965).

[4]William Worthy Day IV, "Physics and Critical Thinking: An Experimental Evaluation of PSSC and Traditional Physics in Six Areas of Critical Thinking While Controlling for Intelligence, Achievement, Course Background and Mobility by Analysis of Covariance" (Ed.D. dissertation, The University of Nebraska Teachers College, 1964), cited in *Dissertation Abstracts* 25 (1964): 4197.

[5]Omar Thomas Henkel, "A Study of Changes in Critical Thinking Ability: A Result of Instruction in Physics" (Ph.D. dissertation, The University of Toledo, 1965), cited in *Dissertation Abstracts* 26 (1965): 5291.

[6]John J. Montean, "An Experimental Study of Discussion Groups in General Chemistry and General Science as a Means of Group Growth in Critical Thinking" (Ph.D. dissertation, Syracuse University, 1959) 20 (1959): 3666-67.

lar educational book *Freedom to Learn* in which he reports case studies of several instructors who have used the investigative approach both in the public schools and on the university level with much success.[7]

How does a student inquire of nature in his search for answers?

Courtesy of ESCP, Boulder, Colorado

It is the tendency of prospective science teachers to think that discovery and inquiry methods are unique to science teaching. This is probably due to the fact that the mathematics and science disciplines have been the most instrumental in applying these approaches. There are, however, other areas of the curriculum which have also adopted these investigative techniques. The social sciences, for example, have prepared inquiry-oriented curricula. In fact, one of the best studies done on inquiry teaching has been a three-year longitudinal study to determine what differences inquiry teaching made on the learning behavior of students. Investigators at the Carnegie-Mellon University found that the inquiry-oriented social studies curriculum significantly increased stu-

[7] Carl Rogers, *Freedom to Learn* (Columbus, Ohio: Charles E. Merrill Publishing Co, 1969).

dents' abilities to inquire about human affairs compared to noninquiry materials.[8]

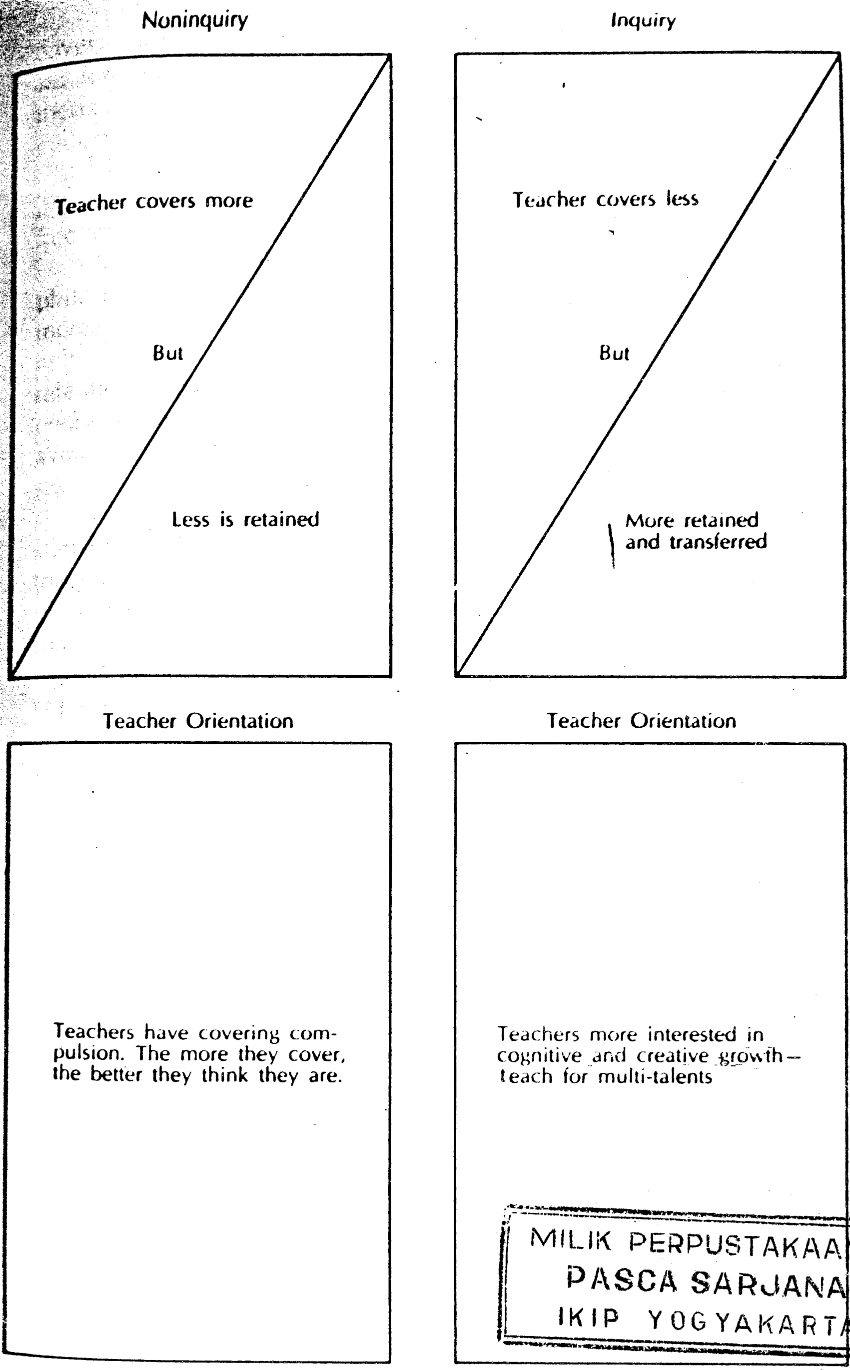
This study is important because it shows that inquiry teaching over a prolonged period (three years) does cause individuals to become better investigators. Often teachers, when they first begin to use this approach, become frustrated and think they are not making sufficient progress. These instructors may suffer from a "covering" compulsion. They feel better as teachers if they cover the subject matter because they have mistaken ideas of the function of teaching. They are surprised to learn that students often don't learn well what was covered by lecture. Teachers can rationalize, as a result, that the students are dumb because they didn't learn or that the class is a slow one, etc. This may save teachers' egos, but the sad consequence of such a compulsion and rationalization is that they don't look for alternatives in instruction. Because a teacher covers something is little assurance students learn it. You can prove this to yourself by covering a topic in a lecture, giving a test over it, and then repeating the test three weeks later. You probably will find out that retention is very low. If this is so, what was taught and what was learned? If you teach well students learn and *retain* what they have studied over a prolonged period of time.

It takes time for students to learn to be inquirers. Because inquiry takes time, not as much is covered in a course. However, more is learned. It is better to allow students time to think and reason and to study some topics in depth than to rush through several varied units. Recall once again the psychological principle—The greater student involvement, the greater the learning—and use it as a fundamental guide for devising your instruction. We would like to close this chapter with one quotation stated by Piaget, who has studied how children become thoughtful, rational beings. He says: "There is no learning without experience." What do you think he means by this statement?

SUMMARY

The modern science curriculum materials are discovery and inquiry oriented. In discovery teaching a student works out in his mind some concept or principle. In the process of discovering, an individual performs such mental operations as: measuring, predicting, observing, inferring, classifying, etc. In inquiry an individual may use all of the dis-

[8] John M. Good, John U. Forley, and Edwin Fenton, "Developing Inquiry Skills with an Experimental Social Studies Curriculum," *The Journal of Educational Research* 63, No. 1 (September 1969): 35.


Noninquiry
Inquiry
Teacher covers more
But
Less is retained
Teacher covers less
But
More retained and transferred
Teacher Orientation
Teacher Orientation
Teachers have covering compulsion. The more they cover, the better they think they are.
Teachers more interested in cognitive and creative growth—teach for multi-talents

covery processes plus those that characterize a mature scientist, such as: formulating problems, hypothesizing, designing experiments, synthesizing knowledge and demonstrating such attitudes as objectivity, curiosity, open-mindedness, respect for theoretical models, etc.

Discovery and inquiry teaching may vary from a relatively structured approach where considerable guidance is provided by the instructor to free investigation where the students originate the problems.

Why teach using these investigative approaches? The advantages philosophically and psychologically appear to be many. These methods increase intellectual potency, shift from extrinsic to intrinsic rewards, help students learn how to learn in investigative ways, increase memory retention, make instruction student centered, build self-concepts, increase expectancy levels, develop multiple, not just academic, talents, avoid learning only on the verbal level, and permit more time for students to assimilate and accommodate information.

Research indicates students taught by these approaches perform significantly better on cognitive tasks involving critical thinking than those taught traditionally.

Teachers often suffer from a "covering" syndrome. If they cover the material they feel their responsibility has been met as a teacher. Because a teacher covers something is little assurance students learn it. Inquiry teaching, because it takes more time, results in covering less than traditional instruction. The retention and critical thinking ability of students in inquiry-oriented classes, however, is greater.

Further Investigation and Study

1. List five words that convey the meaning of this chapter best to you.
2. How would you define the difference between discovery and inquiry teaching? Give an example of each.
3. What are the advantages and disadvantages of investigative types of teaching?
4. How can the investigative approach contribute to building students' self-concepts?
5. What are "expectancy levels" and how might they be changed?
6. Give an example of an instructor doing "Ark and Gork" types of teaching and state how his teaching should be altered to make it more meaningful.
7. In what ways will you try to develop student talents?
8. How does guided differ from free inquiry? How would you prepare students for each?
9. List five examples of your own for free inquiry teaching.
10. What does the present research indicate about investigative teaching?
11. Write a brief essay expressing your feelings about investigative teaching now, compared to the way you felt before coming into this class.
12. What one idea did you get out of this chapter that you think is the most significant?

5

Goals and Objectives

You are about to become a teacher. You have spent several years preparing for entrance into the exciting profession of science teaching. You look forward with anticipation to meeting your first classes and taking responsibility for their learning. Why should you have goals?

Suppose an older teacher says to you, "Forget all that stuff about teaching you learned in college. All that theory just doesn't fit the real world of teaching." Do you still need goals? For what purpose are you meeting your classes? Why are students coming to you to be taught? What is your obligation toward them?

Goals provide guidance and direction. Effective science teaching requires clarification and understanding of your goals, and preparation of objectives. Plans for effective teaching in science have their roots in well-thought-out goals and objectives. Without them it is almost impossible to achieve systematic and measurable results. Many teachers find frustration and disappointment because of the lack of direction accompanying poor or nonexistent goals.

As an example of recent concern for goals and objectives in science education, the Committee on Assessing the Progress of Education has prepared four major goals of science education to guide its efforts.[1] They are:

1. Know fundamental facts and principles of science
2. Possess the abilities and the skills needed to engage in the processes of science
3. Understand the investigative nature of science
4. Have attitudes about and appreciations of scientists, science, and the consequences of science that stem from adequate understandings

Often the words "goal" and "objective" are used synonymously. We prefer to make a distinction. Goals are "broad, general statements, sometimes vague in meaning, which generally shape the character of an educational program."[2] Examples are:

1. To promote interest and appreciation for the contributions of scientists of the past
2. To develop the ability to solve problems systematically

While these goals are laudable, they fall short of providing the teacher with specific teaching objectives. For this reason, recent efforts in science education have emphasized objectives. These are stated in performance or behavioral terms.

Behavioral objectives are objectives written in behavioral terms. They must state how a person is to act, think, or feel.[3] Examples are:

The student should be able:

1. When provided with numerical data concerning the daily growth of plants, to graph the data showing the relationship between height and period of growth.
2. When presented with several relevant and irrelevant bits of information concerning a problem, to select the information needed for its solution and outline a method of attack.

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[1] "National Assessment of Educational Progress", Education Commission of the States, Suite 300, 1860 Lincoln St., Denver, Colorado, 80203.

[2] Robert B. Sund and Anthony J. Picard, *Behavioral Objectives and Evaluational Measures* (Columbus, Ohio: Charles E. Merrill Publishing Company, 1971), p. 1.

[3] *Ibid.*

What do you think are the goals of these students' teacher?

Courtesy of ESCP, Boulder, Colorado

Some of the advantages of behavioral objectives are 1) they help the teacher become more precise in his teaching; 2) they clarify exactly what is expected; 3) the teacher plans more carefully because he knows what performance his students should display after finishing a lesson, unit or course of study; 4) the teacher knows what materials are needed and is able to give more specific help to students in directing them to outside sources of information. The teacher who prepares behavioral objectives finds them very helpful in evaluation. When preparing paper and pencil tests, he can match the questions to the objectives. By deciding on certain criteria of performance, questions can be phrased in such a way that the teacher has precise knowledge of the ability of the student to perform certain tasks. For example, suppose an objective of a unit of work is:

> The student should be able when given data showing the relationship between the pressure and volume of an enclosed gas, to predict either variable when the other is changed independently.

A question used to test the student's ability to predict under the conditions outlined in the objective would be:

The volume of an enclosed ideal gas is 10 liters when its pressure is one atmosphere. Predict what its volume will be when the pressure is two atmospheres.

It is customary to think of behavioral objectives in three different areas, cognitive, affective, and psychomotor. These terms come from the work of Bloom and others who developed taxonomies of educational objectives.[4]

Cognitive objectives are those that deal with cognition—of knowledge, concepts, and understandings. Traditionally, objectives in this area have received far more attention over the years than affective or psychomotor objectives. The subject matter of science—the topics of heat, light, sound, magnetism, plants, animals, and many others—have occupied the attention of science educators. With increased attention to behavioral or performance competencies, the cognitive area becomes fertile ground for the writing of objectives that stress performance in knowledge and conceptual understandings. Lists of sample objectives in this area are given at the end of this chapter.

Affective objectives are those that deal with feelings, interests, and attitudes. Science teachers are becoming increasingly concerned with this area in our schools today. It seems that neglect or lack of attention to the domain of attitudes has resulted in some unexpected outcomes. Students frequently are losing interest in science at a time when scientific advances are unparalleled in history. More and more students are rejecting science, perhaps because of poor understandings of its role in society or because of confusion over the relationships between science and technology.

Writing affective objectives is usually more difficult than writing those in the cognitive area. It requires more care to formulate behavioral criteria for feelings, interests, and attitudes. It is impossible to peer inside the student's head and determine what attitudes lie there. However, certain overt behaviors are indicative of one's attitudes or interests. Some examples of objectives in the affective domain are listed in the publication, *Inquiry Objectives in the Teaching of Biology*.[5]

For the attitude or quality of *curiosity*, related observable behavior might be the student:

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[4]Benjamin Bloom *et al.*, *A Taxonomy of Educational Objectives: Handbook I, the Cognitive Domain* (New York: Longmans, Green Co, 1956).

[5]Richard M. Bingman, Ed., *Inquiry Objectives in the Teaching of Biology*. Mid-continent Regional Educational Laboratory, 104 E. Independence Ave., Kansas City, Missouri, 64106 and Biological Sciences Curriculum Study, University of Colorado, P. O. Box 930, Boulder, Colorado, 80302.

a. Expresses a desire to investigate new things or ideas.
b. Expresses a desire for additional information.
c. Asks for evidence to support conclusions made from scientific materials.
d. Expresses interest in scientific issues in the public domain.
e. Expresses a desire for explanations.

Why does their instructor have these students involved in this activity?

Courtesy of ESCP, Boulder, Colorado

From the above observable behaviors, certain objectives in the affective domain can be constructed. When it is possible to identify sufficient groups of behaviors that characterize individuals holding certain attitudes, the use of affective objectives will become more widespread. The value of considering these possibilities lies in the growing awareness by science teachers of the need for including affective objectives in the planning for teaching.

Psychomotor objectives concern behaviors involving physical manipulation of apparatus, skill development, and proficiency in using tools, such as instruments and devices. In science, many of these desired behaviors are not ends in themselves but serve as means for self-learning.

Since one of the goals of education is to produce individuals who are self-reliant and capable of pursuing learning on their own throughout their lives, the psychomotor objectives occupy an important place in the overall educational endeavor. Although psychomotor objectives play a major role in physical activities, their importance in science classes should not be overlooked. Examples of psychomotor objectives are:

For hand-eye coordination,

1. When provided with a standard mechanical slide rule, the student will be able to find the product of two numbers and express the result in three significant figures.
2. The student will be able to fill a standard buret and release a prescribed amount of liquid.

STEPS IN WRITING BEHAVIORAL OBJECTIVES

The task of writing behavioral objectives can be simplified by following certain steps.

1. *Have your overall goals in mind.* What are your general aims for the lesson or unit you are going to teach? Is it improvement of a skill? Developing the understanding of a concept? Stimulating interest in a new area of science? A combination of these goals?
2. *Select the content desired to achieve the goals of the unit.* In a traditional teaching situation, unit goals may be dependent on the sequence of topics found in a textbook or curriculum guide. But do not let the mere presence of a topical outline dictate your teaching aims. After all, you are attempting to achieve certain goals for a group of students. The topics chosen should be vehicles to achieve these goals. Usually a number of subject matter topics can be used to accomplish the task. Select those that are appropriate in terms of student interests and needs, teacher interest, suitability to the background of the students, and other factors. If you live in a mountainous area, make use of mountain terrain and topography to teach about variations of weather in different locations. Adapt your teaching to local situations. If brachiopods and trilobites can be found in a local limestone quarry, use that resource to teach about fossils rather than discussing forms that can only be found as pictures in books or in exotic collections from laboratory supply houses.
3. *Write tentative statements describing how the student should perform.* Refine these into statements of behavioral objectives that are ex-

pressed in terms of performance criteria. Each objective should include a description of the behavior expected of the student, the conditions under which the student must exhibit the given behavior, and the criteria for successful performance. An example of such a behavioral objective is:

> The student should be able when given a coded weather report in the standard form of seven groups of five-digit numbers, to plot the information correctly on a station circle on a weather map in a space that can be covered by a dime.

What do you think the objective is for this ESCP assignment?

Courtesy of ESCP, Boulder, Colorado

Note that all the conditions for a good behavioral objective are satisfied in the example. Satisfactory performance of the task can be ascertained by the student's ability to interpret the coded message, to place the information in legible form on a weather map; and the criterion of space allowed for the plotted information can easily be checked.

4. *A final step in writing behavioral objectives is to analyze and evaluate them in terms of their overall contribution to the goals of the unit or course.* Without this evaluation, one might easily obtain an imbalance between various levels and areas. Helpful guides in this are publica-

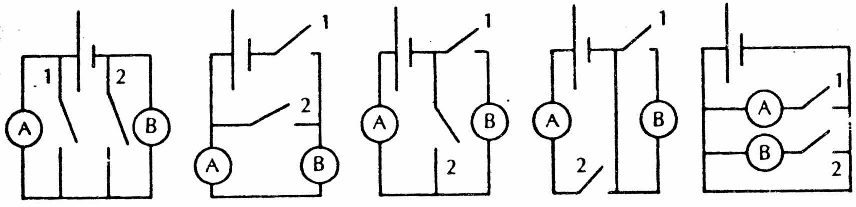
tions by Bloom[6] and Krathwohl.[7] In the cognitive area, Bloom has identified six levels in the hierarchy of educational objectives. They are Knowledge, Comprehension, Application, Analysis, Synthesis, and Evaluation. The latter ones are higher levels of learning and usually require competence at the lower levels for satisfactory performance.

One should be careful to include a large proportion of higher level objectives in order to avoid overemphasis on mere recall types. An example of a higher level behavioral objective (synthesis) is:

> The student should be able, when given a number of elements or parts, to put together the elements or parts in such a way as to constitute a pattern or structure not clearly there before.

A question based on this behavioral objective that might be used to assess the student's ability to perform this level of synthesis is given in the following example.[8]

> A student is given a box on top of which are two identical light bulbs, A and B, and two knife switches, 1 and 2. When only switch 1 is closed, both bulbs light dimly; when only switch 2 is closed, only bulb A lights. A schematic drawing of the circuit might be which of the following?



A B C D E

Successful answering of this question gives evidence that the student is able to synthesize several elements of information, namely, a) that circuits must be closed in order to permit electricity to flow; b) that two bulbs in series increase the total resistance of the circuit and therefore permit less current to flow; and c) that bulbs light up brightly only when the proper amount of current flows through them.

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[6]Benjamin Bloom, *Taxonomy*.

[7]David R. Krathwohl *et al.*, *Taxonomy of Educational Objectives—The Classification of Educational Goals, Handbook II Affective Domain* (New York: David McKay Co., 1964).

[8]John W. Lombard, "Preparing Better Classroom Tests," *The Science Teacher* (October 1965): 33.

Another example of a higher level behavioral objective (evaluation) is:

> The student should be able, in problem situations, to make a quantitative or qualitative judgment about the extent to which material and methods satisfy criteria.

Subject matter should be appropriate for the interests of the students.

Courtesy of Harvard Project Physics, Cambridge, Massachusetts

A question useful in testing this ability is:[9]

> An animal breeder crossed a black guinea pig and a white guinea pig and a litter of three black offspring resulted. The breeder concluded that the black parent could not have been heterozygous (hybrid) for coat color because he thought that any cross between a black heterozygous guinea pig and a white guinea pig would yield a ratio of one white to one black offspring. His conclusion was unsound because he failed to realize that:

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[9]*Ibid.*

a. The black parent might have been a male.
b. Mutations in coat color frequently occur.
c. Coat color in quinea pigs is not inherited.
d. Black coat color is dominant over white in guinea pigs.
*e. Genetic ratios are based on large numbers of offspring.

Perhaps you have noticed one characteristic of behavioral objectives that has not been mentioned up to now. That is the use of "action verbs" in every statement. These words signify the emphasis on performance that is expected of the student. Quite frequently these action verbs appear in the behavioral objectives as infinitive phrases such as "to graph," "to classify," or "to describe." An example is:

> The student should be able, when using the *Handbook of Chemistry and Physics, to interpolate* between two values for temperature correction to be applied to a barometric reading.

A partial list of such action verbs can be found in Chapter 9 "Inquiry Through Laboratory Work," in the section on skill development in the laboratory. Among the important ones are:

Listen	Measure	Select
Search	Demonstrate	Predict
Record	Experiment	Estimate
Compare	Describe	Group
Contrast	Repair	Operate
Classify	Construct	Dissect
Organize	Calibrate	Apply
Outline	Discuss	Infer
Design	Explain	Name
Invent	Report	Identify
Analyze	Write	Translate
Synthesize	Draw	State
Evaluate	Criticize	Graph
Question		

*Correct answer.

Notice the absence in the above list of vague terms such as:

Know	Enjoy	Assimilate
Understand	Believe	Conceptualize
Appreciate		

Using these terms makes it difficult, if not impossible, to provide performance criteria by which the student's work can be assessed. What does it mean "to know"? This word in itself does not give clues as to what kind of performance or behavior the student will exhibit as a result of "knowing." Therefore it is ambiguous and not very useful as an objective statement.

The late Dr. Maria Goeppert Mayer, Professor of Physics, University of California, San Diego.

Courtesy of University of California Public Relations Department

Dr. Dorothy Crowfoot Hodgkin, Nobel Prize Laureate in Science.

Courtesy of Oxford University, Headington, Oxford, England

What can be done to interest more girls in science as a profession?

LISTS OF BEHAVIORAL OBJECTIVES

Teachers and curriculum developers have prepared lists of behavioral objectives for their own respective courses. Many of these have been published for the use of others interested in developing behavioral objectives of their own. In some cases, the published objectives can be used in their original form. In other cases, they can serve as guides for preparation of one's own objectives for a lesson, course of study, or unit. To insure the maximum effectiveness of such objectives, it is important that teachers select them carefully or develop their own to fit the needs of their courses.

Chemistry

One of the most complete lists of behavioral objectives for chemistry courses has been developed by James V. DeRose.[10] Among his recommendations for their use are:

1. The content of high school science courses should be described in terms of behavioral objectives which students can be reasonably expected to achieve.
2. Scientists and educators should identify behavioral objectives in the sciences which are most likely to be educationally significant.
3. Behavioral objectives should be arranged in a hierarchy which permits students the choice of alternate pathways and optional objectives. The multiplicity of objectives, pathways, and options should make it possible for each student to design his own course.
4. Students should receive credit for a course when they have achieved the competencies of a specified minimum set of behavioral objectives rather than when they have spent a specified time with a course.

DeRose's hierarchical arrangement of behavioral objectives for college preparatory chemistry is shown in Figure 13. A partial list of these objectives follows.

At the completion of his study of college preparatory chemistry, the student should be able to:

CI-1 *Identify* and *describe* the system, initial state and final state, given a report of an experiment performed and the observations collected.

CI-2 *State* and *apply the rule* for identifying systems in which a change occurs, given the components of the systems in their initial states and the experimental procedures to follow.

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[10]James V. DeRose, "New Directions for Chemical Education in High Schools", *The 1969 STAR Awards*, National Science Teachers Association, NEA Publication Sales Section, 1201 16th St. N.W., Washington, D.C. 20036.

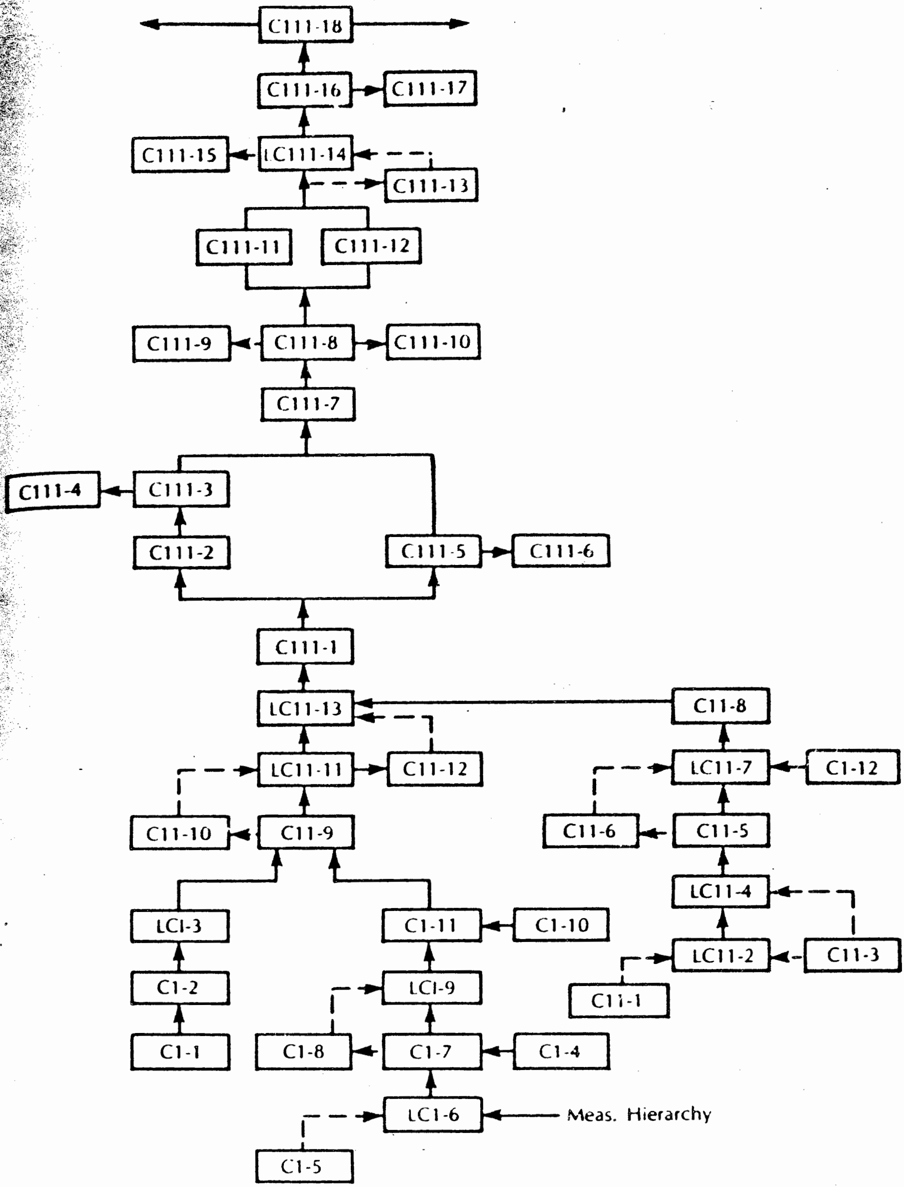


Figure 13 *Chemistry CP Behavioral Objectives Hierarchy (Segment 1)*

Each block represents the designated behavioral objective. The location of each objective in the hierarchy is based on a judgment of the necessary prerequisites. (This hierarchy has not been validated experimentally.) The student proceeds through the hierarchy by following the direction indicated by the arrows attached to the solid lines. Alternate pathways are indicated by the arrows attached to the dashed lines. Alternate pathways provide for flexibility, variation, individualization, and enrichment of the curriculum.

LCI-3 *Demonstrate* the procedure and *apply the rule* for identifying systems in which a change occurs, given the components of the systems in their initial states and the experimental procedures to follow.

CI-4 *Distinguish* between definitions which are operational or conceptual, given a set of definitions.

CI-5 *Construct* a procedure for obtaining the data necessary to calculate the density of a substance in the solid or liquid phase.

LCI-6 *Demonstrate* the procedure and obtain the data necessary to calculate the density of a substance, given a sample in the solid or liquid phase.

CI-7 *Identify* samples of matter as mixtures, solutions, substances, elements and compounds, given observations of the properties of the samples.

CI-8 *Construct* a procedure for distinguishing between a substance and a solution which is based on at least two kinds of evidence, given a liquid which is either a substance or a solution of a solid.

LCI-9 *Demonstrate* the procedure for distinguishing between substance and a solution which is based on at least two kinds of evidence, given the procedure and a liquid which is either a substance or a solution of a solid.

CI-10 *Construct* a line graph, given a set of paired data for two variables.

CI-11 *Identify* the smallest number of different substances represented in a set of samples, given either mass-volume and/or time-temperature data for each sample in the set.

CI-12 *Distinguish* between observations and hypotheses (theories).

CII-1 *Construct* a procedure for obtaining data to determine the solubility of a given solid substance in water.

LCII-2 *Demonstrate* a procedure for obtaining data to determine the solubility of a given solid substance in water.

CII-3 *Construct* a procedure for obtaining data to determine the effect, if any, of temperature on the solubility of a solid substance in water.

LCII-4 *Demonstrate* a given procedure for obtaining data to determine the effect, if any, of temperature on the solubility of a given solid substance in water.

CII-5 *Demonstrate* the preparation of an aqueous solution of specified volume and concentration, given a solid substance, the volume of the solution, and the concentration in grams of solute per unit of volume of solution.

CII-6 *Construct* a procedure for obtaining data which can be used to test the hypothesis that a given aqueous solution of a solid is homogeneous with respect to subdivision.

LCII-7 *Demonstrate* a procedure for obtaining data which can be used to test the hypothesis that a given aqueous solution of a solid is homogeneous with respect to subdivision.

CII-8 *State* and *apply the rule* for determining either the mass of solute, volume of solution or concentration of a solution, given values for the other two.

CII-9 *Identify* systems in which interaction between the initial components can be assumed upon mixing, given mass and volume data of the systems in their initial and final states and systems composed initially of either two solids, a solid and a liquid, or two liquids.

CII-10 *Construct* a procedure for qualitatively determining which, if any, of two substances in the initial state of a system is present in the final state, given solutions of substances which produce precipitate when they are mixed.

LCII-11 *Demonstrate* a procedure for qualitatively determining which, if any, of two solutions in the initial state of a system is present in the final state, given the procedure and two solutions which produce a precipitate when they are mixed.

CII-12 *Construct* a procedure for obtaining data to determine the relationship (mass ratio) if any, between the mass of either of two initial components and the mass of the precipitate produced after mixing, given solutions of the initial components and their concentration in grams of solute per unit volume of solution.

LCII-13 *Demonstrate* a procedure for obtaining data to determine the relationship (mass ratio) if any, between the mass of either of two initial components and the mass of the precipitate produced after mixing, given the procedure and solutions of the initial components and their concentration in grams of solute per unit volume of solution.

Biology

A useful document for preparing behavioral objectives in biology has been published jointly by the Mid-continent Regional Educational Laboratory and the Biological Sciences Curriculum Study.[11] Arranged according to expected behaviors in certain modes of inquiry, such as the taxonomic mode, the antecedent-consequent mode, the structure-function mode, the regulation-homeostasis mode, the self-regulatory mode, and the biological situation mode, several characteristic behaviors have been identified. Among these are:

The student will:

1. Ask or recognize questions.
2. Make, identify, or recognize observations in order to answer questions.
3. Identify or recognize ways data must be handled to answer questions.
4. State a problem in terms of each of the principles of inquiry.
5. Describe the experimental design appropriate to each type of problem.

A group of sample behavioral objectives which if achieved give evidence of the understanding and use of the major factors in inquiry is as follows:

1. Problem formulation

    a. Given a structured or open situation, the student will identify at least one discrepant event.

    b. Given problems which involve finding causes, the student will eliminate those that are not feasible.

    c. Given a problem, the student will redefine it within the limits of available time, tools, and observations.

[11]Bingman, Ed., *Inquiry Objectives*, p. 20.

d. Given instructions to do so, the student will communicate to his teacher the extent to which he has utilized the following resources as aids in selecting a problem: teacher consultation, text, other students, other resource persons, books, periodicals, and research reports.

2. Formulating hypotheses

a. Given a problem statement in researchable terms, the student will list any factors which may be related to the problem on the criterion: "anything that comes to mind."

b. Given a list of factors said to be possibly related to a certain problem, the student will order the factors with respect to relevance to the problem.

c. Given a problem statement in researchable terms, the student will formulate an hypothesis.

d. Given an hypothesis, the student will clarify it.

e. Given a group of hypotheses derived from one problem, the student will eliminate duplication.

f. Given a group of hypotheses, the student will communicate his decisions as to their testability and relevance.

3. Designing a study

a. Given a problem, and/or hypothesis(es) the student will communicate all the variables that might operate during a test of the hypotheses.

b. Given a problem and hypothesis, the student will communicate the single independent variable that must be studied to test the hypothesis.

c. Given a problem, hypotheses, and list of all other operant variables, the student will communicate a plan to control the independent variables.

d. Given instructions to prepare the design of an experiment that could be executed by others in the same way it was to be executed by the student himself, the student will prepare such a design.

e. Given instructions to do so, the student will produce evidence that he has planned for systematic observation of descriptive data.

f. Given instructions to select the most appropriate mathematical operation in a certain set of circumstances, the student will so select.

4. Executing the plan of investigation

   a. Given instructions to execute a plan which includes gathering and processing data from a controlled experiment, the student will:

      1. Produce evidence that he is gathering and processing data according to the plan.
      2. Use gathering techniques (or instruments), processing forms, and statistical procedures, in accordance with whatever error considerations and assumptions they may have, to clarify the error consideration above for data collection.
      3. Review the techniques (or instruments) and procedures by indicating the extent to which each functioned as planned during execution of the plan.

5. Interpreting the data or findings

   a. Given processed data and a synopsis of the problem, hypotheses, and the controlled experimental design that produced it, the student will:

      1. Correctly identify the assumptions of the study.
      2. Use the results of at least one of three other studies provided to interpret the data or findings.
      3. Given a set of data, communicate a generalization.
      4. Given data and a generalization, solve a problem using the generalization.
      5. Use at least two different means of presenting the data to bring out different features of the data.
      6. Given that there is a conflict in the data, communicate the particular conflict.
      7. When instructed to draw conclusions from data, known by the teacher to be insufficient, withhold judgment until further data are available.
      8. Will select from a list the one interpretation which is limited to the restrictions of the hypothesis.

6. Synthesizing knowledge gained from the investigation

   a. Given limited antecedent-consequent conclusions, supporting data, and other experimental reports, the student will demonstrate that he has compared these data and conclusions with data and conclusions of similar and/or replicate studies.

b. Given limited antecedent-consequent conclusions, supporting data, and comprehensive knowledge of match of one study's data and conslusions to similar and/or replicate studies, the student will list applications of this study.

c. Given limited antecedent-consequent conclusions, supporting data, comprehensive knowledge of match of one study's data and conclusions to similar and/or replicate studies, and instructions to resolve a new and related problem, the student will predict the nature of the new problem's solution.

d. Given a report of a research study, including tentative conclusions, and given theories that seek to account for such phenomena as were considered problematic in the study, the student will communicate that the conclusions are (are not) validly related, i.e., accounted for, not contradictory to the current theories, etc.

7. Differentiation of the various principles of inquiry

a. Given examples of the various principles of inquiry, the student will select the example which is antecedent-consequent, label it as such, and separate this particular study from the others by listing its differences and by stating that it involves finding causes of effects.

b. Given a problem which involves finding a cause, the student will state which principle of inquiry is appropriate.

c. Given a completed study in one principle, the student will list changes which would apply throughout the study if a different principle of inquiry were used.

Following is a list of sample cognitive and psychomotor behavioral objectives for high school biology, prepared by a graduate class in science education at the University of Northern Colorado:

Cognitive

Laboratory

The student should be able to:

1. Observe and record differences in structure of a given group of organisms (specimens) on a prepared form.
2. Separate plants from animals on the basis of the recorded data.

3. State whether or not the two hypotheses were supported by the data.
4. Formulate an hypothesis about thé relationship between snail and elodea.
5. Devise an hypothesis about the carbon cycle including oxygen.
6. Predict the shape of the growth curve on both types of graph paper if the populations were to continue to increase at the same rate for an indefinite period of time.
7. Calculate the number of yeast organisms growing in a given culture tube by using a dilution method.
8. Identify the variables and controls in the experiments.
9. Identify the producers and consumers in the investigation, and note producers are green plants.
10. Identify the variables and controls involved in the activities of this unit.
11. Prepare a growth curve on arithmetic paper (graph) when provided with the census data of a given population for ten years.
12. Prepare a growth curve on semilog graph paper under the same conditions as previous objective.
13. Prepare a graph showing the relationship of the age of the culture to the density of organisms.
14. Explain why a real population could or could not grow according to the growth curves obtained in this exercise.
15. Explain the differences in the graphs of a theoretical population and the graph of a real population.
16. Explain the probable causes of the fluctuations in a real population.
17. Explain how one could increase the reliability of the data collected from a real population.
18. Explain the major differences between graphs of normal and hypothetical populations and why this difference exists.

Psychomotor

Laboratory

The student should be able to:

1. Collect data on the germination of seeds and record the data on charts provided.

2. Construct bar graphs from data collected from petri dishes containing seeds.
3. Clean lenses and mirrors properly.
4. Carry a microscope properly.
5. Adjust and focus the microscope by bringing the objective lens close to the slide without touching it and moving the objective away from the slide only while viewing.
6. Mount, stain, observe, and draw starch grains, given slides, cover slips, and a potato.
7. Measure microscopic objects using the microscope with a rule having millimeter intervals.

The student should be able to, when:

8. Given slides, cover slips, and specimens, prepare a wet mount for observation.
9. Given slides, cover slips, and yeast solution, prepare a wet mount and draw the cells.
10. Given a slide, cover slip, and a mixed culture of protozoans, draw the organisms observed after preparation of a wet mount.

Affective Objectives

Affective or attitudinal qualities associated with science learning are usually difficult to identify. However certain observable behaviors may be taken as indicative of attitudes or feelings held by the students. A list of such behaviors which might be used constructively in attitude assessment has been prepared by the Mid-continent Regional Educational Laboratory and Biological Sciences Curriculum Study.[12]

ATTITUDE OR QUALITY	RELATED OBSERVABLE BEHAVIOR
	The Student:
I. Curiosity	A. Expresses a desire to investigate new things or ideas.
	B. Expresses a desire for additional information.
	C. Asks for evidence to support conclusions made from scientific materials.
	D. Expresses interest in scientific issues in the public domain.

[12] *Ibid.*, p. 34.

ATTITUDE OR QUALITY	RELATED OBSERVABLE BEHAVIOR
	E. Expresses a desire for explanations.
	The Student:
II. Openness	A. Demonstrates willingness to subject data and/or opinions to criticism and evaluation by others.
	B. Seeks and considers new evidence.
	C. Expresses the realization that knowledge is incomplete.
	D. Expresses knowledge of the tentative nature of conclusions as products of science.
	The Student:
III. Reality orientation	A. Demonstrates knowledge and acceptance of his limitations.
	B. Expresses awareness that change is the rule rather than the exception.
	C. Expresses awareness of several sources of knowledge.
	D. Expresses awareness of the fallibility of human effort.
	E. Expresses belief in science as a means of influencing the environment.
	F. Does not alter his data.
	G. Demonstrates the realization that research in science requires hard work.
	H. Demonstrates awareness of the limitations of present knowledge.
	I. Expresses awareness of the historic development of patterns of inquiry and of the processes and characteristics of science.
	J. Demonstrates belief that the search for desirable novelty should be tempered by awareness and understanding of traditional concepts.
	The Student:
IV. Risk-taking	A. Willingly subjects himself to possible criticism and/or failure.
	B. Expresses his opinions, feelings, or criticisms regardless of the presence of authority.

ATTITUDE OR QUALITY	RELATED OBSERVABLE BEHAVIOR
	C. Participates freely in class discussions.
	D. Indicates a willingness to try new approaches.
	The Student:
V. Objectivity	A. Indicates a preference for statements supported by evidence over unsupported opinion.
	B. Indicates a preference for scientific generalizations that have withstood the test of critical review.
	The Student:
VI. Precision	A. Indicates a preference for coherent statements.
	B. Seeks definitions of important words.
	C. Demonstrates sensitivity to the appropriateness of general and/or specific statements in a given context.
	D. Expresses the need to examine a problem from more than one point of view.
	The Student:
VII. Confidence	A. Expresses confidence that he can achieve success at inquiry.
	B. Demonstrates willingness to take "intuitive leaps."
	The Student:
VIII. Perseverance	A. Pursues a problem to its solution or to a practical point of termination.
	The Student:
IX. Satisfaction	A. Expresses satisfaction with the process of inquiry.
	B. Expresses confidence that his inquiry experience will enable him to attain future goals.
	The Student:
X. Respect for theoretical structures	A. Demonstrates awareness of the importance of models, theories, and concepts as means of relating and organizing new knowledge.
	B. Demonstrates awareness of the importance of currently accepted theories and concepts

ATTITUDE OR QUALITY	RELATED OBSERVABLE BEHAVIORS
	as a framework or basis for the emergence of new knowledge.
	C. Demonstrates awareness of the importance of scientific procedures to the generation of new knowledge, theories, and concepts.
	The Student:
XI. Responsibility	A. Is active in helping to identify and establish learning goals.
	B. Demonstrates willingness to work beyond the assignment.
	C. Insists upon adequate evidence on which to base conclusions.
	D. Suggests changes to improve procedure.
	E. Shows respect for the contributions of others.
	F. Demonstrates willingness to share knowledge with others.
	G. Offers a rationale for criticism.
	H. Initiates action for the benefit of the group.
	The Student:
XII. Consensus and collaboration	A. Demonstrates willingness to change from one idiom, style, or frame of reference when working with others.
	B. Calls upon other talent from within the group when opinions and help are needed.
	C. Seeks clarification of another person's point of view or frame of reference.

The Junior High School

The Riverside School study under the auspices of the California State Department of Education has defined some goals and behavioral objectives for the junior high school.[13] Samples of these are found in the

[13]*Planning a Continuous Science Program for All Junior High School Youth*, Guidelines for Designing and Implementing Contemporary Science Curricula for Grades 7-9. Revised preliminary edition prepared under an NDEA contract with the California State Department of Education by the Office of Riverside County Superintendent of Schools with the assistance of the Council of California Science Teacher Organizations, Office of County Superintendent of Schools, Riverside, California, 1967.

Appendix. The goals are indicated by Roman numerals and terminal objectives by Arabic numerals.

SOME CRITICISMS OF BEHAVIORAL OBJECTIVES

While many educators have recognized advantages in specifying instructional objectives in behavioral terms, others have objected strenuously to the present movement. Some of their arguments are presented for consideration by the reader.

1. There may be a tendency to overemphasize trivial behaviors because it is easier to state objectives for specific behaviors than for overall general objectives.

Proponents of behavioral objectives view this as an advantage. Recognition of *specific* objectives will assist teachers in preparing general objectives in operational terms because they will be able to scrutinize all objectives carefully and weed out the trivial ones.

2. Teachers may be inhibited in capitalizing on spur-of-the-moment teaching opportunities if they have many specific behavioral objectives prepared.

Should not *all* classroom activities contribute toward realization of teaching objectives? Having clear behavioral objectives will permit the teacher to judge quickly the relevancy of the unexpected activity.

3. It is impossible to measure precisely certain educational objectives.

This is certainly true. However, evaluation goes on regardless. Should teachers not have at their disposal the best possible *objective* measures based upon performance standards to assist them in the enormously complicated task of evaluating pupil achievement and growth?

4. Teachers customarily express their objectives, if done at all, in vague general statements.

It is true teachers are generally quite vague about their objectives; however, there is no reason to continue this state of affairs. To provide quality education, it is reasonable to expect teachers to adopt improved methods of planning and teaching, which include better knowledge of one's objectives.

5. Behavioral objectives, being specific, imply that the teacher may be accountable for success in achieving them in his classes.

This is a frequently used argument which expresses a feeling of being threatened in one's teaching role. However, the use of precise objectives can work to the teacher's advantage here. It is no longer necessary to hide behind vague, general objectives with many interpretations. Instead, performance criteria and substantiated results can provide parents and school administrators with evidence rather than mere speculation as to the outcomes of class work.

SUMMARY

It is important to have goals and objectives for science teaching. Without objectives, teaching becomes a confused and directionless experience, frustrating to the teacher and ineffective for the students.

Recent years have seen increased attention to objectives stated in behavioral or performance terms. Good behavioral objectives include the expected performance of the student, the conditions under which the performance can be expected, and the level of attainment needed to satisfy the objective. Behavioral objectives are often divided into cognitive, affective, and psychomotor types. The first pertains to conceptual understandings or knowledge objectives. The second refers to attitudes, feelings, interests, and appreciations. These objectives are difficult to write and evidence of their achievement depends on observations of overt behaviors that are indicative of the affective trait or quality. Psychomotor objectives refer to skills and competencies that involve manipulation, muscular coordination, or sensory achievements.

A characteristic of good behavioral objectives is a statement using "action verbs" signifying performance in observable or measurable terms. Vague terms such as "know" or "understand" should be avoided in writing behavioral objectives.

Many groups have prepared lists of behavioral objectives for their classes or curriculums. Such lists should be used as guides for constructing similar objectives for oneself. Occasionally the lists may be used in the original form but care must be exercised in choosing objectives suitable to the overall goals of one's course.

The movement toward use of behavioral objectives is significant. While critics have cited certain pitfalls to be avoided, the overall effect appears beneficial. Teachers are more conscious of the performances they wish to expect from their students. Evaluation becomes more precise. Progress toward the attainment of goals is more easily measurable. Science teaching assumes a quality that is more satisfying and defensible.

Further Investigation and Study

1. Write behavioral objectives for a unit of science you plan to teach. Classify them as cognitive, affective, and psychomotor. Use the format suggested in the chapter.
2. For each of the behavioral objectives prepared for the cognitive and psychomotor domains in Question 1, write a suitable test question giving students an opportunity to demonstrate the performance expected in the objective.
3. For each of the affective behavioral objectives prepared in Question 1, write three expected overt student behaviors giving evidence that the objective has been achieved.
4. Prepare a ten-minute talk you might deliver to a parent-teacher group describing the advantages and disadvantages of using behavioral objectives in science classes.

*In actual life the real value is something we experience as connected with the reality of our activity, and any verbal discussion is on a quite secondary level.**

6

Questioning for Inquiry

The essence of inquiry teaching is arranging the learning environment to facilitate student-centered instruction and giving sufficient guidance to insure direction and success in discovering scientific concepts and principles. One way a teacher helps a student obtain a sense of direction and use his mind is through questioning. The art of being a good conversationalist requires listening and insightful questions. A good inquiry-oriented teacher is an excellent conversationalist. He listens well and asks appropriate questions assisting individuals in organizing their thoughts and gaining insights.

An inquiry-oriented teacher seldom tells but often questions. This is so because by asking questions, the teacher assists the student in using his mind. A properly given question is a hint. For example, a student is studying a pendulum, but hasn't discovered that its frequency is related to its length. The instructor moves about the class and notices the student seems to be having difficulty. He goes to him and asks a series of questions. Listed below on the left margin are the questions he asked. On the right side of the page is an analysis of what the instructor is doing.

*Rollo May, *Man's Search for Himself*, (New York: The New American Library, 1967), p. 186.

Notice the instructor did aid the student through artful questions to make his own discoveries and to use his mind. The teacher did not steal the thrill of discovery from the student, but he did facilitate it.

Proper questioning is a sophisticated teaching art. To practice it, a teacher must perceive well where the thoughts of a student are. In order to do this, the instructor must switch from the classical concept of teaching—telling—to listening and questioning and being open to the students' thoughts. Consequently, his emphasis changes from teaching to student learning. After perceiving the student's difficulty, he has to formulate a question which will be a challenge yet give guidance to the student. In order to do this, the instructor must know what it is he is trying to teach in a conceptual and humanistic way and adapt his question so it is appropriate to the student. As the teacher moves about the class, he constantly has to adapt this procedure from student to student. This requires fantastic awareness and ability on his part. No wonder so many teachers fall back into the classical mold of teaching. But to move about a classroom in this manner is to truly individualize instruction, teach for the "person," and, if done constantly in a positive setting, humanize instruction.

Good questioning practices are involved in all areas of science instruction as indicated in the list below:

WHERE IS QUESTIONING INVOLVED IN SCIENCE?

1. Discussion
2. Laboratory Exercises
3. Demonstrations
4. Student Worksheets
5. Audio-Visual Aids
6. Evaluations

TYPES OF QUESTIONS

Questions may be planned before class or spontaneously arise because of student interaction. It is always wise to plan a series of questions before entering an inquiry-oriented class. The mere fact that you have done this contributes to your questioning ability. Having thought about the questions gives you direction and a sense of security thus furthering your ability to carry on a discussion.

An inquiry-oriented teacher must remain constantly flexible. Even though he has planned a series of questions, he must be willing to deviate from them and formulate new ones as he interacts with students. These unplanned, spontaneous questions may be difficult to create at first, but through attempting to develop good questioning techniques, an instructor becomes more sophisticated at devising them and is more likely to interact appropriately with students.

What processes of science are these students using?

Courtesy of Harold Pratt, Science Supervisor, Jefferson County, Colorado

What Must Be Considered Before Questioning?

Before you devise your questions you should decide the following:

1. What talents are you going to try to develop?
2. What critical science thinking processes will you try to nurture?
3. What subject matter objectives do you want to develop?
4. What types of answers will you accept?

How Well Do You Recognize Good Questions?

Read the questions on page 113 and mark them according to whether they are poor, fair, good, or excellent:

	Poor	Fair	Good	Excellent
1. Why do roots suck water?				
2. Why does water seek its own level?				
3. Are all big trees the same size, shape and age?				
4. How does a siphon work?				
5. How do seeds sprout?				
6. How does soap clean?				
7. What will happen if clothes are soaked with a bleach before instead of after washing?				
8. How can the bleaching action be accelerated?				
9. If ethylene glycol prevents avalanches, what other chemicals do you suspect might also prevent avalanches?				
10. If you were going to repeat the experiment with yeast, how would you improve it?				
11. How would you design an experiment to____?				
12. If you have a straight line graph indicating a relationship between population growth and time but the period ends at 2 days, what could you say about the population at 4 days?				
13. How would you define a magnet operationally?				
14. How could you be more certain about the conclusions you made from the data?				
15. What do you think will happen to a potted geranium plant if it is placed near a window?				
16. What evidence does the process of diffusion contribute to the molecular theory?				

	Poor	Fair	Good	Excellent
17. Look at the culture plates and describe what you see.				
18. Place the organisms into any two groups you wish.				
19. If the distance is increased between two masses in Newton's gravitational formula, what will happen to the force?				

Self-Analysis of Types of Questions

Written below are several questions related to the questions asked above. Read each and attempt to answer it. Keep your answers and refer back to them again after completing this chapter to see how well you did.

1. What three questions above do you think are the best to ask?
2. Which are teleological or anthropomorphic questions?
3. Which questions require the student to analyze?
4. Which questions require the student to synthesize?
5. Which questions require the student to evaluate?
6. Which questions are convergent?
7. Which questions are divergent?
8. Which questions require the student to demonstrate in his response the processes of science?
9. Which questions require students to reason quantitatively, and what are they required to do?
10. Which questions require creative responses?
11. Which questions require the student to formulate an operational definition?
12. Which questions require a student mainly to observe?
13. Which questions require a student mainly to classify?
14. Which questions require a student to demonstrate experimental procedure?
15. Which questions require a student to formulate a model?
16. Which questions require a student to hypothesize? How would you classify most of the questions on this sheet?

17. Which question would an authoritarian personality most likely guess at if he didn't know the answer?
18. Which of the following two types of questions suggests a test?
    a. How do seeds sprout?
    b. What is needed for seeds to sprout?
19. It has been said that "how" questions do not lead to experimentation. Comment on this.

After completing the above, compare and discuss your answers with other students in the class.

THERE ARE LEVELS OF EDUCATIONAL OBJECTIVES

In 1948 a group of college examiners attending the American Psychological Association Convention in Boston, Massachusetts, met and discussed the possibility of preparing a framework to assist test constructors. They agreed that this could probably be devised by developing a classificational system of educational objectives. You have already encountered in the previous chapter the classification system they wrote.

Just as objectives can be classified by this taxonomy so can questions. Refer back to the questions asked above and classify them, in the left-hand margin, according to the taxonomy. After doing this list five of the best questions and decide why you believe they are good. Bloom's abbreviated taxonomy is given again to help you. An example of how you might use it is shown on page 116 as a guide.

BLOOM'S TAXONOMY

Cognitive Domain	Affective Domain
Evaluation	Receiving
Synthesis	Responding
Analysis	Valuing
Application	Organization
Comprehension	Generalized Set
Knowledge	

Questions requiring responses from the higher levels of the hierarchy are more desirable because answering them involves more critical and creative thinking and indicates a better understanding of the concepts.

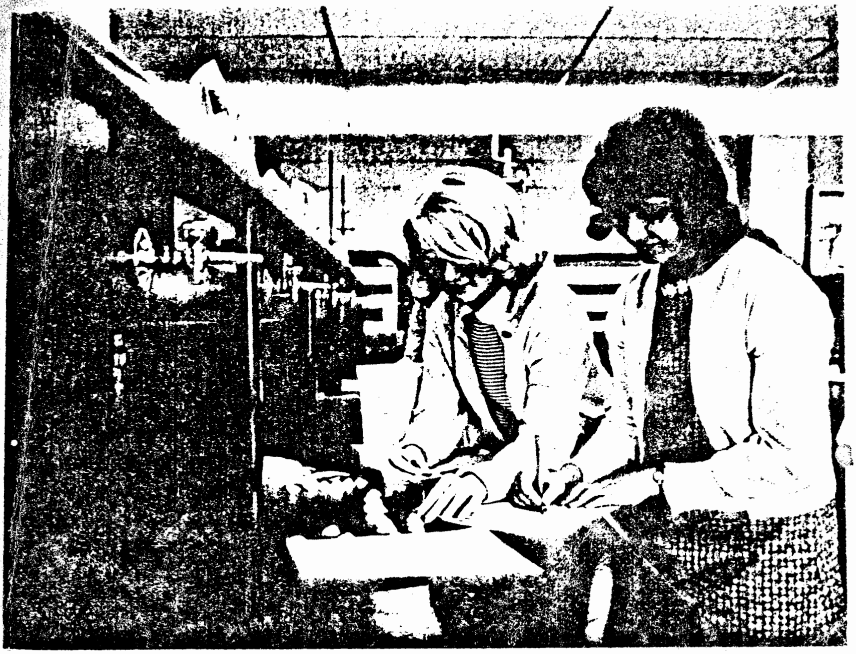
USING BLOOM'S TAXONOMY TO CLASSIFY QUESTIONS	
Classification	
Knowledge	1. How many legs has an insect?
Synthesis	2. What hypotheses would you make about this problem?
Application	3. Knowing what you do about heat, how would you get a lid off a jar that won't unscrew easily?
Analysis	4. What things do birds and lizards have in common?
Comprehension	5. Define operationally a magnet.
Evaluation	6. If you were going to repeat the experiment how would you do it better?
Valuing	7. What is your interest about earth science now compared to when you began the course?
Valuing	8. What do you feel about this film?

Another way to classify questions is to do so by using the processes of science. This approach insures that the basic structure of science and critical thinking is taught. More about using this system is illustrated in Chapter 9 on laboratory work. Refer to it for a complete list of the processes. Also shown below is a guide of how you might classify questions using science processes.

SCIENCE PROCESSES

1. Hypothesizing
2. Inferring
3. Measuring
4. Designing and Experiment
5. Observing
6. Setting up equipment
7. Graphing
8. Reducing experimental error, etc.

CLASSIFYING USING SCIENCE PROCESSES	
Classification	
Observing	1. What do you observe about the landscape?
Hypothesizing	2. What do you think will happen to the solution when I heat it?
Designing an Experiment	3. How would you determine the absorption of the different wave lengths of light in water?
Graphing	4. How would you graph this data?
Setting up Equipment	5. Obtain the following equipment and set it up as directed.
Reducing experimental error	6. How many measurements should be made in order to report accurate data?
Inferring	7. What conclusions can you make from the data?



What processes of science are these students using?

Courtesy of Bob Waters, University of Northern Colorado

CONVERGENT AND DIVERGENT QUESTIONS

Another way to classify questions is to determine whether or not they encourage many answers or just a few. Questions allowing for a limited number of responses and moving toward closure or a conclusion are called Convergent. Questions allowing for a number of answers are called Divergent. They provide for wider responses plus more creative, critical-thinking answers. In an inquiry discussion it is generally desirable to start with very divergent questions and move toward more convergent ones if the students appear to be having difficulties. Read the questions below and classify them in the left margin as divergent or convergent. Compare your answers with those given in the Further Investigation and Study section at the end of the chapter.

CLASSIFICATION	DIVERGENT/CONVERGENT QUESTIONS
	1. What do you think I am going to do with this apparatus?
	2. What conclusions can you make from the data?
	3. Can anything else be done to improve the growth of the plants?
	4. Is heat an important factor in the experiment?
	5. Do you think the salt precipitated because the solution was cooled?
	6. Which of these three rocks is harder?
	7. What can you tell me about the geology of this area from the picture?
	8. Would you say you have sufficient data?
	9. What ways can you make the lights burn with the wire, switch, and power supply?
	10. What things can you tell me about the biological make-up of this earthworm from your observations?

What questions above are the most convergent? What answers are possible for these questions? What words start these sentences? How would you change the sentences to make them more divergent?

Generally speaking, convergent questions, particularly those requiring only a yes or no answer, should be avoided. This is so because they allow for fewer responses thereby giving students little opportunity to think critically. The fundamental purposes of using the inquiry approach is to stimulate and develop critical thinking, creative behavior, and multiple talents. Convergent questions certainly do little to achieve this end. Remember in an inquiry investigation it is not as important that the student gets the right answer than that he has a chance to use his mind so that he may "BECOME" more of a person. Learning to think rationally and creatively does much to increase our self-concepts. Many teachers are so concerned with getting the right answer that they prevent students from using their minds. Even though a student may come up with wrong conclusions, he still has had a mental experience in thinking about the problem. To have this experience probably is more important than a right answer. We as teachers would, of course, like for a student to use his mind and obtain the correct answer as well! However, recall for a moment a mathematics teacher who only accepts the answer to a problem as being correct, ignoring the procedures used in obtaining it. The student may have used very good thinking processes to obtain the answer, yet misplaced the decimal point. Is the teacher justified in saying that the student hasn't learned because he hasn't the right answer? The student will probably never have that problem again, but he undoubtedly will have many situations requiring him to use similar logical strategies. It is the thinking that is most important! The teacher who doesn't reward this may stifle students.

Avoid Teleological and Anthropomorphic Types of Questions

Teleological (Greek—*Teleos*—an end) questions are those implying natural phenomena has an end or purpose. The word anthropomorphic comes from two Greek words: *anthropos*, meaning man, and *morphos*, meaning form. An anthropomorphic question implies some natural phenomenon has the characteristics of man. For example, such a question might state that some natural phenomenon has a "want"—rocks fall because they "want" to—however, only man can want. Listed below are some examples of these two types of questions. With these definitions in mind, classify the questions.

CLASSIFICATION	TELEOLOGICAL/ANTHROPOMORPHIC QUESTIONS
	1. How do you think bacteria feel when ultra-violet light is shined on them?
	2. Why does water seek its own level?
	3. Why do plants want to grow toward the light?

4. Why will a body in motion continue to want to stay in motion?
5. Why is the end of evolution to become increasingly more complex?

Why do you think these questions should be avoided? What do they do as far as developing critical thinking, leading to further investigation, and how do they contribute to misconceptions? The answers to these questions should be obvious to you and need no discussion here.

QUESTIONING FOR MULTI-TALENT

Although the procedures thus far have mainly emphasized the importance of cognitive questions, this is not to say other types are not important. Teachers should spend a considerable amount of time formulating talent-oriented questions so as to come to know their students.

We believe that you should not only determine talent, but help to manifest it. This means that you reward students for all types of talent. Some teachers and administrators may argue that the only function of a science teacher is to develop scientific awareness. It is our view that this awareness will occur to a higher degree if a student has opportunities to manifest his best talents, thereby building his self-concept and developing more positive feelings about science. Some examples of talent-oriented questions are listed below.

QUESTIONING TO DISCOVER TALENT

Question	Questioning For:
1. Who would be willing to draw for extra credit a mural to be hung in our laboratory?	Artistic Talent
2. Who wants to help organize the field trip?	Organizing Talent
3. Who would write a short article for the school paper about the science fair?	Communicating Talent
4. In what ways can we convey to the rest of the school how exciting biology, earth science, chemistry, physics, etc., are?	Creative Talent

5. Who would like to be in charge of the social activities for the science picnic?	Social Talent
6. Who would like to be in charge of planning our investigations of the pond community throughout the year?	Planning Talent

Teachers should also ask questions to find out students' interests. What "turns them on"? Determining this helps the instructor in planning more relevant lessons. Questioning individuals about what they like in personal conversations also helps to convey to the students your interest in them as people and not as sponges to soak up scientific information.

Piaget has pointed out that proper questioning gives insights into a student's thought patterns. In order to do this, the instructor must hypothesize how the student is thinking, then pose questions to see if he is correct. When the student responds, the hypothesis may be reinforced or need further investigation. He may have to formulate a new hypothesis and construct questions to determine its validity. This type of questioning is particularly necessary when the student seems to be having difficulty in discovering or conceptualizing. Excellent teachers in mathematics, physics, chemistry, etc., often use this approach to diagnose students' thinking-process difficulties in order to help them resolve problems.

WAIT-TIME AFFECTS THE BEAUTY OF THE RESPONSES

Mary Budd Rowe[1] and her collaborators have done an extensive study of the questioning behavior of teachers. In their analysis of taped classroom discussions, they discovered that teachers, on an average, wait less than a second for students to reply to their questions. Further investigations revealed that some instructors waited on an average of three seconds for students to answer questions. An analysis of student responses revealed that teachers with longer wait-times—three seconds or more—obtained greater speculation, conversation, and argument than those with shorter wait-times.

Dr. Rowe found further that when teachers were trained to wait five seconds, on the average, before responding the following occurred:

[1] Mary Budd Rowe, "Wait-Time and Rewards as Instructional Variables: Influence on Inquiry and Sense of Fate Control," *New Science in the Inner City*, Teachers College, Columbia University, New York (September 1970). Unpublished paper prepared for the symposium at Kiel, Germany.

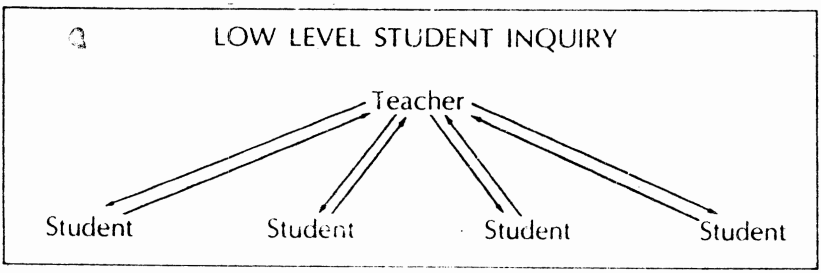
1. Students gave longer and more complete answers instead of short phrases.
2. There was an increase in speculative, creative thinking.
3. The number of questions and experiments suggested increased.
4. "Slow" students increased in participation.
5. Teachers became more flexible in their responses to students.
6. Teachers asked fewer questions, but the ones they asked required more reflection.
7. Students gave a greater number of qualified inferences.
8. Teacher expectations for student performance changed. They were less likely to expect only the brighter students to reply.

Dr. Rowe believes the expectancy levels of students are more likely to change positively if they are given a longer time to respond. She has also found that the typical pattern of discussion: teacher — student — teacher can be altered by training instructors to get student — student — teacher responses. This pattern will occur particularly well when students are involved in some controversy, e.g., how best to go about designing an experiment or what conclusion can be drawn from data.

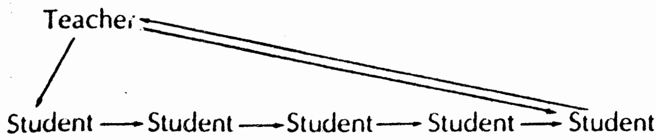
For inquiry teaching to occur, it seems reasonable that most instructors should attempt to increase their wait-time tolerance so that students may have more opportunities to think and create.

GOOD DISCUSSIONS ARE STUDENT CENTERED

Most teachers when they are involved in a class discussion dominate it to a considerable extent; an inquiry class should be student centered. This means that the teacher's talking should be at a minimum. Note the two diagrams of discussion interaction in a class:



HIGHER LEVEL STUDENT INQUIRY



It is no easy task to develop techniques so that the second type of interaction operates. How would you as a teacher get the second pattern to operate in your classes?

VARIOUS TYPES OF QUESTIONS

General Questions to Involve Students in Investigations

1. What do you notice...,i.e., this picture, equipment, the environment?
2. What will happen if...?
3. If this is so then...?
4. This is so if and only if what?

Questions to Stimulate Creative Responses

1. How would you do it better?
2. What would you do to improve the situation?
3. What if you changed the size, shape, color, of some object?
4. What if you added or took something away from the object?
5. How would you design an experiment to find out?
6. What hypotheses would you make about...?
7. How would you go about improving the experiment?
8. What would be a better way to organize...?
9. How would motion affect the...?
10. What other uses can you think of for this object?
11. If you were going to design a better...what would you do?
12. If you were going to collect better data, how would you do it?
13. If different materials were used in the experiment what would happen?

Questions to Review a Biography

1. What stimulated the scientist to do the work he did?
2. From where did he get the ideas for the problems he studied?
3. What experimental procedures did he devise?
4. What effect did society have on his work?
5. What effect did his work have on society?
6. Why do you think he was psychologically "turned on" to do the work he did?
7. What did he achieve?
8. What kind of self-concept do you think he had and how did he build it?
9. How did his work contribute to devising better problem-solving procedures, thereby improving the scientific method?
10. In what ways did he follow or deviate from what is thought as being the scientific method?
11. How did this book affect your feelings about science and scientists?
12. Science is a human enterprise. How does the book illustrate this idea?
13. What did reading this book do to you as a person?

Questions to Stimulate Students to Analyze Experiments and Invitations to Inquiry

1. What was the nature of the problem?
2. What procedures were used in solving the problem?
3. How could these procedures have been improved?
4. What were the hypotheses?
5. What factors or variables were involved in the experiment?
6. What other factors might have been involved in the experiment?
7. How did this experiment contribute to your understanding of...?
8. What assumptions were involved?
9. What scientific principles were involved?
10. How were the terms defined?
11. What data was collected?
12. What was the control?

13. How was the data interpreted?
14. What statistical weaknesses were involved?
15. What possibilities are there for further experimentation?

RESEARCH INDICATES GOOD QUESTIONING PAYS OFF

Research indicates that teachers specifically trained to ask questions stressing the higher cognitive levels of Bloom's Taxonomy do significantly better in constructing them than do those not having this experience.[2] It must also be remembered that Bloom's Taxonomy is used by national testing organizations as a guide in formulating their questions. It is obvious that students having had manifold experiences in answering questions on all cognitive levels will be better prepared to encounter achievement and college board tests, etc. With this knowledge in mind, your task is to change your questioning behavior so as to facilitate better learning and human development. This is a great challenge particularly since there is no end to the degree of sophistication your questioning skill may attain.

SUMMARY

Basic to inquiry teaching is the ability of the teacher to ask questions to stimulate and facilitate creative and critical thinking and manifest multiple talents. Inquiry types of questions may be involved in all areas of science teaching such as, discussion, laboratory demonstrations, student worksheets, visual aids, and evaluations. An instructor should plan his questions before class but remain flexible and adapt his instruction as dictated by student interaction. Before outlining the question, a teacher should decide what talents, critical thinking processes, and subject matter objectives he hopes to develop and the answers he will accept.

Questions may be classified as convergent or divergent according to Bloom's Taxonomy, by the science processes, and/or by the multiple talents they are trying to develop. Divergent types of questions and those requiring more cognitive sophistication should be stressed. Teleological, anthropomorphic questions, and those that could be answered by yes or no responses should be avoided.

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[2]Virginia M. Rogers, "Varying the Cognitive Levels of Classroom Questions in Elementary Social Studies: An Analysis of the Use of Questions by Student Teachers," Ph.D. Dissertation, The University of Texas, Austin, 1969, and O. L. Davis, Jr. *et al.*, "Studying the Cognitive Emphases of Teachers' Classroom Questions," The Research and Development Center for Teacher Education, University of Texas, Austin, 1969.

The time a teacher waits for a response, called "wait-time," is very important. Most teachers wait, on an average, less than one second. Five second average wait-time results in more responses by slow learners, more creative answers, more complete sentence answers, a greater number of questions, and more suggestions for experiments.

The chapter gives suggestions for questions to get students involved in investigations, to stimulate creativity, and to review a biography.

Research indicates that teachers trained in questioning techniques do change their questioning behavior in the classroom, asking questions requiring greater cognitive ability. Teachers who do emphasize higher level types of questions are more likely to have their students do better on national tests since these tend to test for all cognitive levels.

Further Investigation and Study

1. Observe a normal conversation and classify the questions asked according to the classificational system suggested in this chapter.
2. Write some discussion questions and classify them according to Bloom's Taxonomy, multiple talents, and science processes.
3. List as many words as possible which when used as the first word of a sentence would require only yes or no answers.
4. Return to the list of questions asked in the chapter and your answers and review them to see if you would like to alter any of your answers.
5. Read the booklet *Developing Questioning Techniques—A Self-Concept Approach*, Arthur Carin and Robert B. Sund, Charles E. Merrill Publishing Co., 1971.
6. Lead a small discussion and have someone check your wait-time and how well you get students to talk to students instead of students to teacher to student.

ANSWERS TO QUESTIONS ON PAGE 118

Divergent questions: 1, 2, 6, 7, 9, 10

Convergent questions: 3, 4, 5, 8

COGNITIVE MICROTEACHING EVALUATION FORM

The following scale on page 128 is to be used to check the kinds of cognitive skills an instructor requires in teaching students. The word Cognition comes from the Latin *cognoscere* meaning to come to know and is used by modern-day behavioral scientists to refer to mental thought processes. All of the following are critical thinking cognitive processes. Some of them, however, have been placed under a special category because they have greater implications for scientific problem solving.

COGNITIVE — CRITICAL THINKING PROCESSES

	No. of times					
Applying						
Assuming (asking children to recognize assumptions)						
Comparing						
Criticizing (analysis)						
Decision making (analysis of what to do)						

SCIENTIFIC PROCESSES

	No. of times					
Classifying						
Collecting and organizing data						
Designing and investigation						
Formulating models						
Hypothesizing or predicting						
Inferring or making interpretations						
Measuring						
Observing						
Operational definition						

SELF-EVALUATIONAL INSTRUMENT FOR RATING YOUR QUESTIONING ABILITY

Use a cassette tape recorder to record a discussion you lead. Listen to the tape and note the following:

1. Check if you asked what students knew about the topic before starting the discussion.
2. Check once each time you ask a convergent question. Check:
3. Measure how many seconds you wait for a response. Time in sec.:
4. Check each time you develop student-student rather than teacher-student interaction. Check:
5. Check each time you ask an Affective Question. Check:
6. Check each time you reinforce an answer without saying the response is correct. Check:
7. Check each time if you do not stop discussing a point when the right answer is given but still ask students if there are other answers. Check:
8. Check each time you ask a question requiring science process thinking, i.e., hypothesizing, designing an experiment, inferring, etc.
9. Check each time you interrupt a student not giving him time to complete his thought.
10. Rate yourself as a good listener below:

1	2	3	4	5	6	7	8	9	10
Poor					Average				High

11. Check each time you paraphrase a student's statement to clarify or focus for others on the topics.
12. Measure how much class time you devoted to routine—roll taking, announcements, etc.—student involvement, and teacher talk. (Time in sec.)

    Routine:

    Student Activity or Involvement:

    Teacher Involvement:

Evaluate your responses above and list those things you most want to change about your instruction.

Rate yourself again or have a student or aide do it and note your improvement.

*We know too much for one man to know much, we live too variously to live as one. Our histories and traditions—the very means of interpreting life—are both bonds and barriers among us.**

J. Robert Oppenheimer

7

Discussion as a Means of Inquiry

DISCUSSION VERSUS LECTURE

June Truesdale, a first-year teacher, came storming into the faculty lounge. She said, "Wow, if this day represents teaching, you can have it!" Mrs. Pollack asked, "What happened to upset you?" Mrs. Truesdale said, "The students in my class just don't want to learn. They don't pay attention and are always causing discipline trouble. I had to send three students to the dean's office last period." Mrs. Pollack, an experienced and sympathetic colleague, said, "June, you must be doing something wrong. What did you do last period?" June replied she was lecturing to her general science classes on light. Mrs. Pollack asked, "How long did you lecture? Did you do any demonstrations? Did you allow the students to do anything?" June answered no to all of these questions. Mrs. Pollack then suggested that June not lecture to the students but have a discussion instead. She said, "Why don't you ask some interesting questions about light? For example, ask how do you know there is glass in my eye glasses? What evidence do you have that there is glass present without touching the glass? Does all the light hitting the eye

*From a speech delivered at the University of Colorado, Summer 1963.

lenses go through them? How do you know it isn't all going through? What causes a rainbow? What does a flat mirror do to light? What does a curved mirror do to light?" Mrs. Pollack then suggested the class take a mirror and discuss what happens to light as it hits it. "Don't lecture to them but demonstrate and discuss. You will find far more interest and less discipline trouble."

Most experienced science teachers would have given Mrs. Truesdale the same kind of advice. Good science teaching requires student-involved activity. The trouble with Mrs. Truesdale's using the lecture approach was that students were seldom involved except in absorbing information. In a lecture, many students "tune the teacher out," become bored, listless, and eventually cause discipline problems. The attention span of junior high school and high school students for a lecture is, at best, short. This doesn't mean that a few minutes of lecture may not be desirable. An experienced teacher can use it effectively for ten to twenty minutes, particularly if he is using several visual aids such as the chalkboard, overhead projection, models, or apparatus. A lecture on how to use the microscope, for example, may work well, especially if the students have microscopes before them and are encouraged to locate the parts being covered in the lecture.

ADVANTAGES OF DISCUSSION

Students become more interested because they are involved. Discussion, because it involves students more than lecture in the learning process, is a more desirable approach for class procedures. Since an objective of modern science instruction is to teach science as a process with emphasis on the cognitive development of the individual, students must have the time and opportunities to think. Thinking is something one does! A student can't think unless he is given opportunities to do so. The presentation of problems in a discussion requires students to think in order to formulate answers. A teacher, on the other hand, who tells students all about a subject presents no problem to the student except boredom. In addition, the students have been robbed of an opportunity to use their minds. All they have to do is soak up information and memorize it.

Discussion is more likely to develop inquiry behavior. A discussion leader interested in developing inquiring behavior seldom gives answers but asks questions instead. Students in answering questions learn to evaluate, analyze, and synthesize knowledge. They are often thrilled to discover fundamental ideas for themselves.

The teacher receives feedback. A discussion gives feedback to the teacher. An astute discussion leader learns quickly from the student comments their comprehension of the topic. He then guides the discussion, moving it rapidly when students understand the information and slowing it down when they have difficulty. A lecture-oriented teacher seldom knows what students are comprehending. He may belabor a point the class long ago understood or speed through information few understand. *One of the greatest mistakes a beginning teacher can make is to assume that the lecture method will work well in a secondary school.*

HOW TO LEAD A DISCUSSION

Leading a discussion is an art, an art not easily learned. There is nothing more exciting to see than a master teacher carrying on an interesting and exciting discussion. How can you bring students to this point? Excellent class discussions do not just happen. The inexperienced instructor may think he will walk into a class and talk about a subject "off the top of his head." After all, doesn't he know more about the subject than the students? It's true he may know about the material, but he is faced with the problem of getting students to discover it and to develop their talents. This takes preparation, as much preparation as any other class procedure requires. The first step in preparing for a discussion is to determine what it is you wish to accomplish, your objectives. Next, outline questions you think may help students to reach these objectives. A good discussion leader uses the "What do you think?" approach to learning. He asks such questions as suggested in the chapter on questioning. For example he might ask:

1. Why did you do this experiment?
2. What did the data show?
3. Why did you use this approach?
4. How would you go about finding answers to this problem?
5. What other ways could you find the answer?
6. What good is this in your daily life?
7. What mental steps did you make in solving the problem?
8. How many variables were involved in the experiment?
9. How do you feel about science?

Spend Time Analyzing Thought Processes

Every discussion should stimulate critical and creative thinking. You should spend time analyzing the types of questions you will ask in a discussion to insure that they require the manifestation of these abilities. By doing this, you will indicate to your students a belief in their *becoming* more exciting persons and contribute positively to their expectancy level about critical thinking. Showing students they are performing relatively sophisticated mental operations, i.e., inferring, hypothesizing, evaluating data, etc., will encourage them to accept the idea that they can use their minds to derive answers to relatively sophisticated problems. We only come to believe we are good thinkers by having success in thinking and receiving feedback about this from others. Furthermore, a teacher who involves students in tasks requiring thinking and shows them how they are developing their minds builds positive student self-concepts.

Steps to Follow in an Inquiry Discussion

An instructor should enter the class with an attitude of letting students work out the answers. A simple design for planning an inquiring discussion is as follows:

1. Present a problem.
2. Encourage students to formulate hypotheses or give evidence for answers to the questions. A problem is stated as follows:

   A burning candle is placed upright in a pan. There is some water in the pan. The candle is then covered with a glass container.
3. Show how the experiment is set up by projecting a transparency of it on a screen. Some types of questions to ask are: What will happen to the candle when it is covered? What else will happen to the apparatus as this is done? What would happen if the candle were lengthened, the size of the jar above it were increased, the amount of water in the container holding the candle were decreased? How would you find out?
4. After the students have progressed this far, have some student reflect back on what has been said and more or less summarize the good points of the discussion. As a discussion leader, you might at times have to assist a student in doing this by asking again: What was the problem?

   Review the cognitive processes they used in solving the problem. Ask: What hypotheses were made? What was the best hypothesis and why? How were the conclusions reached? On what are they based? What is required to make better conclusions?

Questions Must Be Directed at the Students' Level

A neophyte discussion leader often starts a discussion with too difficult a question. If there is no response to a question, the teacher should rephrase it, make it simpler or lessen its depth. This procedure may have to be followed several times before there is any response. A question implies an answer. If the question is too vague the students may not respond; rephrasing a question may give them some insight. Leading a discussion by questioning and giving no answers is a skill which brings great satisfaction, but to be an astute questioner requires practice and a keen awareness of the students' comprehension. The sophisticated discussion leader is able, by the questions he asks, to guide students toward understanding the concepts and principles involved in the lesson or experiment. The questions must be of sufficient depth to require critical thinking and not so simple as to require only a yes or no answer.

Eye contact is an important aspect in leading a discussion. A teacher's eyes should sweep a class like a searchlight, constantly looking for boredom, a student with an answer or a question, or one with a puzzled look. Eye contact helps to give the instructor feedback as well as to motivate students to think and participate in the discussion. It further conveys the impression that you are more interested in the students you are teaching than in the information being covered.

A Discussion Started in a Novel Way Gains Attention

A motivational technique useful in beginning a discussion is to start it with an interesting demonstration. For example, a container of blood sitting on a demonstration desk can do wonders for beginning a discussion about blood or the circulatory system. Burning a candle can lead to a discussion of a number of scientific concepts and principles. A good rule to follow is to start a discussion with a percept if possible. Not all discussions will lend themselves to this procedure, but those that involve the discovery of a concept almost always do.

Use Overhead Projectors When Appropriate

The use of overhead projection with transparencies helps to concentrate the class's attention on clarifying a problem. For example, focusing students' attention on some of the approaches to devising a classification scheme can be done easily on an overhead projection. Use different-colored paper cut to various sizes and shapes and ask students how they would group the materials. A discussion can arise from the demonstration of such cognitive processes as analysis, discrimination, and ordering. Another demonstration using the overhead projector might include a discussion of magnetism and magnetic lines of force; using a magnet and iron filings sprinkled on top of transparent plastic sets the stage for a discussion of the properties of magnetism.

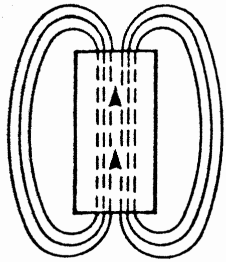


Figure 14 *Overhead Projection of a Magnet with Iron Filings around it*

General rules to follow in giving discussions are:

1. Create an atmosphere in the class in which questions are not only welcomed but *expected*. Be a warm person, open and receptive.
2. Try to bring in the interests of the students as much as possible in the discussion.
3. When you give reinforcement do it positively as much as possible. Seldom use negative reinforcement. Say: "That's a good answer, that's right, you have the idea," "Good, you're thinking; keep it up, you have something there," "Who would like to react to this answer?" Do not ignore the answers of students; always give some recognition to their answers. No response by the teacher should be a form of negative reinforcement. If students have the wrong answer, do not say, "That's wrong; no, that answer is no good." But rather say, "Well, that is not quite right," "You may have something there, but I am not sure I understand the point," or "Good, you are thinking; but that is not what I was thinking about."
4. When you encourage a student to think, evaluate the product on the basis of his level of comprehension. Even when you, with a more extensive background, are aware that the idea given is either incomplete or incorrect, accept it or even praise it, if it indicates that the student has made effective use of the information he was expected to know at that stage of the course.
5. Praise a student for being a good listener when he calls attention to a mistake you have made.
6. Try to remember previous comments in leading a discussion and interrelate them. If at all possible give recognition by referring to the name of the student who made the comment. For example, a teacher in responding to the idea of a student says, "John believes there are other factors determining the rate of

expansion of a metal beside temperature. George has just suggested that possibly humidity and air pressure may have a minor effect." The teacher has acted as a summarizer for two students' views and has given them recognition by using their names.

7. Maintain a positive and accepting attitude. Your attitude in leading a discussion does much to determine the quality of that discussion. If you walk into a class feeling and looking very serious and with the weight of the discussion on your shoulders, the students' response will be mild. However, if you start a discussion with the attitude that you and the students are going to have fun wrestling with ideas, the response is more likely to be impressive. In leading a discussion with adolescents, you must be able to laugh at yourself; discreet use of humor captures interest and gains participation.
8. State when questions arise for which science does not yet provide an adequate explanation, that there is no answer yet. This gives students insight into avenues of research which we still need to explore.
9. Restate, as warranted, the answer a student gives prior to going on to your next remarks. Doing this often allows other students time to think about what they would give as an answer.
10. Call upon students who do not indicate a willingness to answer, as well as those who do.
11. Do not rush discussions. Remember the major reason for having them is to give students time to think. When there is silence during a discussion, this may be the period where the most thinking is going on. Remember as Dr. Rowe has pointed out a desirable wait-time is on an average five seconds.

Special Precautions in Leading a Discussion

At times the following suggestions are proper, but the teacher should give serious consideration to their potential disadvantages:

1. Toss a question back to a class when it is asked of you. Have another student repeat the question in its entirety. Ask a student to speak up so that the entire class can hear. Ask a student to research an answer to the question on his own.
2. Encourage the entire class to take notes.
3. Avoid the appearance of carrying on a private conversation with the person who asked the question.
4. Deliberately let your eyes roam over the entire class while giving the answer.

5. Use questions requiring hypothesis formation.
6. Avoid sarcasm.
7. Encourage students to seek recognition before answering or have them be courteous of another and wait until that person finishes before they respond.
8. Don't let students make derogatory remarks about another student's question or answer since this is demeaning to the person.
9. Suggest an individual conference with the student when:
   a. The degree of difficulty in answering is above the level expected of the class as a whole.
   b. The subject matter involved bears little relation to the key ideas being stressed.
   c. The answer is both detailed and lengthy.
   d. The time spent in answering the question may destroy the sequence of thought being developed.

TESTING YOUR JUDGMENT

Secondary students are similar to college students in that they are continually trying to psychoanalyze the instructor. "What does he know?" "Is he smart?" "Does he really like this material we are studying?" "How sharp is he?" "Does he like me?" "How accepting is he?" "Is he tolerant?" These questions are constantly in the minds of the students until they come to know the instructor as a person. He should be aware, therefore, of the fact that students sometimes are testing his judgment. They may ask questions to which they already know the answers to see how he will respond. They may try to deviate from the purpose of instruction to see whether they can get the teacher off the track. They may try to bring up controversial subjects not because they are interested in them but to see the teacher's reaction. Students will not generally do this; most of the time they are sincerely interested in learning. However, an instructor who does not recognize these deviations or who reacts poorly to this type of questioning usually is poorly prepared in subject matter or is not very accepting of adolescent behavior. A well-prepared teacher with a sense of direction and belief in the value of a person will have little trouble recognizing these attempts and will laugh at the situation. He might say, "I know what you're doing. You're trying to get us off the subject, and that's OK for a little bit; but let's get back to the problem. The problem was . . . ." An instructor should not feel that he must know the answers to all questions. It is impossible for a teacher to know all about his subject. When asked questions he cannot answer, he can ask the class whether any of them knows the answer or how the answer could be determined and admit to the class he doesn't know it. Students don't really expect the teacher to know everything, and in fact they enjoy having the teacher learn with them.

SPECIAL DISCUSSION TECHNIQUES

Invitations to Inquiry

The Biological Science Curriculum Study has produced in its *Biology Teachers' Handbook* forty-four class-discussion outlines under the title "Invitations to Inquiry." The main purpose of these is to *involve students in the strategies of solving scientific problems*—not to teach science subject matter. The invitations engage students in the processes of solving problems as scientists actually do. A typical outline for an invitation is as follows:

FORMAT FOR AN INVITATION

1. Present a problem to the students.
2. Ask how they would go about solving it.
3. Describe the experimental design the scientist actually used.
4. Ask the students what hypotheses they would make about the experimental results.
5. Give the students the data the scientists collected.
6. Ask: What conclusions can you make about this data?
7. Ask: If you were the scientist what would be your next problem and why?

BSCS authors state of invitations, "The primary aim is an understanding of enquiry. It is mainly for the sake of this aim that the active participation of the student is invoked. Both practical experience and experimental study indicate that concepts are understood best and retained longest when the student contributes to his own understanding."[1]

Example of an Invitation

An example of a simple invitation, similar to one produced by BSCS, inviting students to form hypotheses and design experiments is given

[1]Joseph J. Schwab *et al.*, *Biology Teachers' Handbook* (New York: John Wiley & Sons, 1963), p. 47.

below. Note that the steps in writing it are provided on the left-hand side of the chart as a guide so that you can easily follow them in writing your own.

STEPS IN WRITING AN INVITATION	INVITATION
Problem is presented. Students are asked to design an experiment.	A farmer had a reasonably high mortality rate among his chicks. He wanted to decrease this rate but was not sure what to do. What would you do to insure that fewer chicks died?
More text is given to the student. Students are asked to hypothesize.	The farmer came to the conclusion that the possible cause of death might be related to the heat source keeping the chicks warm at night. He suspected that some of them got cold, but there was ample room for the chicks to get near the white lamp heat source. He wondered whether the lamp itself might have something to do with death of the chicks. What would you do to test this idea?
More information given. Students asked to design an experiment.	After a period of time he decided to use different colors of light bulbs in the lamp to see what happened. If you were going to test this hypothesis, how would you go about it?
More data is given. Students asked to make inferences.	Out of a flock of twenty-five chicks in each of the incubators he obtained the following mortality over a three-day period. *Red Light Source* — 1 chick died *Blue Light Source* — 2 chicks died *White Light Source* — 3 chicks died What do the above data indicate? What can you definitely conclude from this data? How could you be more certain of your answers? How certain are you from this experiment that light was the cause of the mortality? What are some of the other factors that might have caused chick mortality?
Students suggest and design experiments.	What experiments would you do to find out?

The above invitation involves students in understanding a problem, outlining experiments, forming hypotheses, interpreting data, and drawing conclusions. It illustrates the application of the scientific method to a realistic situation.

How to Design an Invitation to Inquiry

You can easily make your own "invitations." The steps are as follows:

1. Decide what your science processes and subject matter objectives are.
2. State a problem related to your objectives. The idea for problems can come from actual scientific research reported in journals.
3. Devise questions giving students opportunities to set up experiments, make hypotheses, analyze and synthesize, and record data. Stress the understanding of science as a process and the cognitive skills involved.
4. Write the invitation as a series of steps. Insert in different parts of it additional information to help the student progress in depth into the topic or methods of research.
5. Evaluate your invitation comparing it with the science process list on page 116 and rewrite it to include more of these processes.

Invitations to inquiry can be written for various levels of learning. They should stress as much as possible the development of the students' cognitive abilities. Students should, in addition to the science processes, also learn the necessity for having a control and cause-and-effect relationships, learn when to use quantitative data and how to interpret quantitative data, learn the role of argument and inference in the design of experiments, etc.

Write an invitation! The first invitation you write probably won't be very sophisticated, but in the process of writing it you will gain insight into how to construct them plus a better understanding of how to involve students in understanding science as a process.

Invitations Should be Open Ended and Suggest Research

Invitations to inquiry can be used to suggest open-ended experiments. For example, if a class finishes an "invitation" concerning the necessity of light for seeds during germination, the teacher might ask:

What other factors might affect germination?
What difference in germination would there be if the temperature, humidity, light intensity, air pressure, amount of oxygen present, or magnetic field were altered?

In devising questions of this type the instructor should attempt to have students learn what factors, such as those listed below, may be involved in any experimental situation.

EXAMPLES OF EXPERIMENTAL VARIABLES

light	food supply	electricity or electrical field
heat	gases present	pH
sound	pressure	
humidity	magnetic field	
numbers and types of reactants	motion	
	gravity	

By studying these projects, the students gain insights into the limitations of science, see science as a process, and develop confidence in their own ability to become scientific. The vicarious nature of the inquiries can be altered to active involvements in research activities by having students become aware of the number of variable factors involved in an experiment and how they can be modified, and by then having them devise an experiment to do in the laboratory.

After students have been involved in several invitations, have them individually or in small groups write some themselves. This has been done with considerable success and enjoyment by secondary school students. This approach works particularly well if you encourage students to construct invitations on topics of vital concern to them, i.e., pollution, drugs, sex education.

Single-Topic Film Invitations to Inquiry

Single-topic films have been produced by BSCS as "Invitations to Inquiry." These films, which have no sound, present a problem and ask questions. The students use the visual material to discover the answer to the problem. The single-topic film *Social Behavior of Chickens*, produced by BSCS, shows a group of chickens in a cage. A problem is posed: What evidence is there of the social behavior in chickens? Questions are asked by the teacher from time to time relative to what the students are viewing. Students can spend considerable time viewing a frame, since these are produced in eight-millimeter cartridges for the small eight-millimeter projector, and a single frame can be stopped for an extended period. As the film progresses, the chickens are paired in ten possible combinations. The students observe each of these combinations and record their information. They are then asked to make interpretations. The class discusses the results. The films may be rerun to verify the conclusions or to answer some question or doubt. The role of the teacher is essentially that of questioner and leader of a discussion, aided by the projection of visual material. The visual material is the inquiring medium.

PICTORIAL RIDDLES

Another technique for developing motivation and interest in a discussion is to use pictorial riddles. These are pictures or drawings made by the teacher to elicit student response. A riddle is drawn on the blackboard or on poster board or is projected from a transparency, and the teacher asks a question about the picture.

Pictorial Riddles are relatively easy to devise. They can be as simple or complex as a teacher desires. In devising a riddle, an instructor should go through the following steps:

1. Select some concept or principle he wishes to teach or elevate.
2. Draw a picture or show an illustration which demonstrates the concept.
3. An alternate procedure is to change something in a picture and ask students to find out what is wrong in the picture. An example might be a picture of a big man being held up on a seesaw by a small man. Ask, "How is this possible?" Or show a farming community in which all of the ecological principles are misapplied and ask what is wrong with what has been done in the community.
4. Devise a series of questions, related to the picture, which will help students gain insights into what principles are involved.

There are two general types of pictorial riddles:

1. Riddles showing an actual situation. The instructor asks why it occurred. Figure 15 is of this type.
2. Riddles where the teacher manipulates something in a drawing or a series of drawings and then asks what is wrong with the diagram. Figure 17 is an example of this type.

Shown below are several examples of riddles and some questions that might be asked about them.

PICTORIAL RIDDLE (Physical Science)

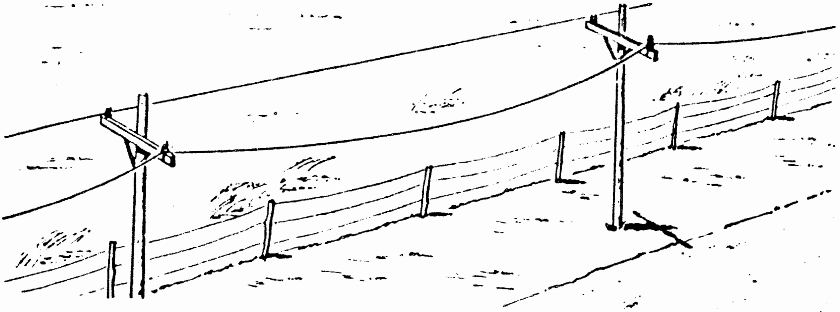


Figure 15

1. What do you notice about the things in this picture?
2. What is similar in the picture?
3. Why do the fence and the telephone line appear similar?
4. Why wouldn't you expect to find the two telephone lines so different?
5. What do you suspect the season of the year would have to be for each line and why?
6. What does temperature have to do with the appearance of the telephone lines and why?
7. What time of year would you expect to see the sagging telephone line and why?

See Figure 16 on Page 145

1. What factors would affect how the needle goes through the coin?
2. What would temperature have to do with it?
3. How would the motion of the needle affect its penetration of the quarter?
4. What type of quarter would be the easiest to send a steel needle through?
5. What kind of needle would be the best to go through a quarter?
6. What other questions can you think of related to this riddle?

PICTORIAL RIDDLE (Physical Science)

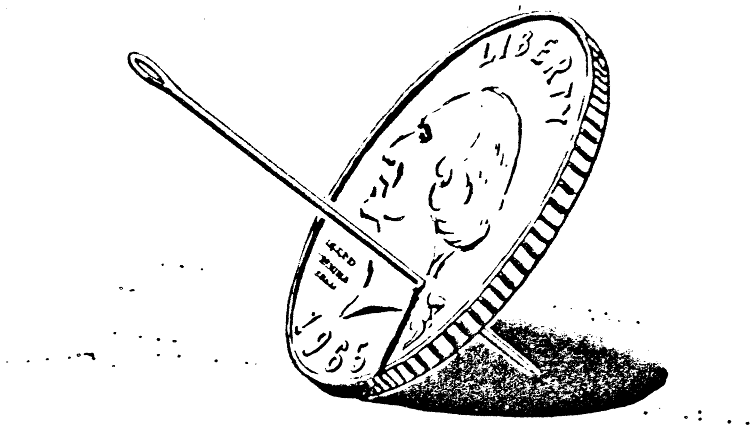


Figure 16

PICTORIAL RIDDLE (Biology)

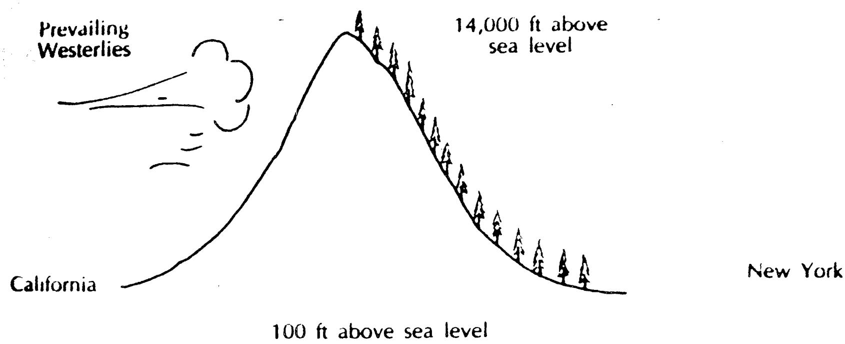


Figure 17

1. What questions can you ask about this riddle?
2. What is wrong with this diagram?
3. Where do pine trees grow?
4. Why do they grow where they do?
5. If you were going to change the riddle to make it more accurate, what would you do and why?
6. What does the wind have to do with the ecology of the area?
7. Where would you expect to find the most and the least amount of vegetation on the mountain? Why?

8. How could you change this riddle to teach some additional science concepts?

PICTORIAL RIDDLE (Physical Science)

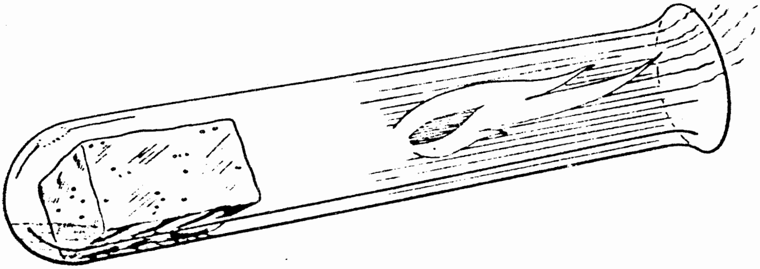


Figure 18

1. What do you think is happening in this riddle?
2. How can there be a flame in the presence of an ice cube?
3. What is burning in the test tube?
4. Why wouldn't this burning melt the ice cube?
5. If the cube in the bottom were dry ice, how would it affect the burning?
6. What would have to be done in order to set up this demonstration?
7. What kinds of demonstrations can you think of using dry ice?
8. If you were going to alter this riddle to make it more intriguing, what would you do?
9. What other questions could you ask?

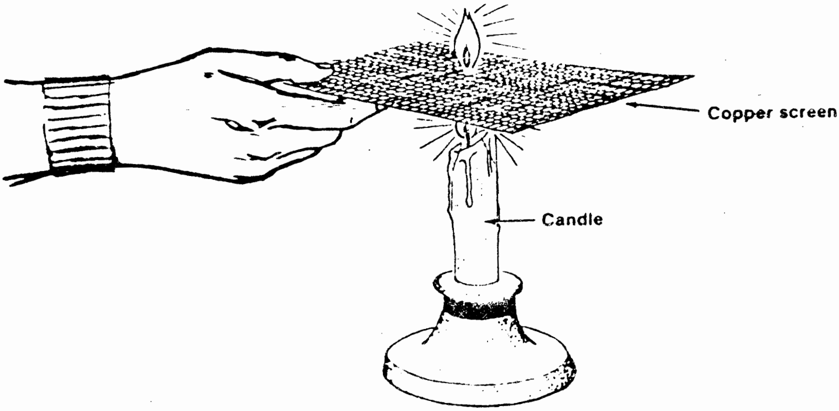


Figure 19

See Figure 19 on Page 146

1. When would the above be possible?
2. When wouldn't it be possible?
3. What evidence is there from what you observe that a candle gives off gas?
4. How would a different type of metallic screen make any difference?

Teacher's note:

Concepts involved in the riddle are:

1. Copper is an excellent conductor of heat.
2. Gas must reach kindling temperature in order to burn.

Placing a copper screen above the candle removes heat from the flame immediately. Unburned gases come through the screen but will not burn; however, if they are ignited above the screen, they will burn.

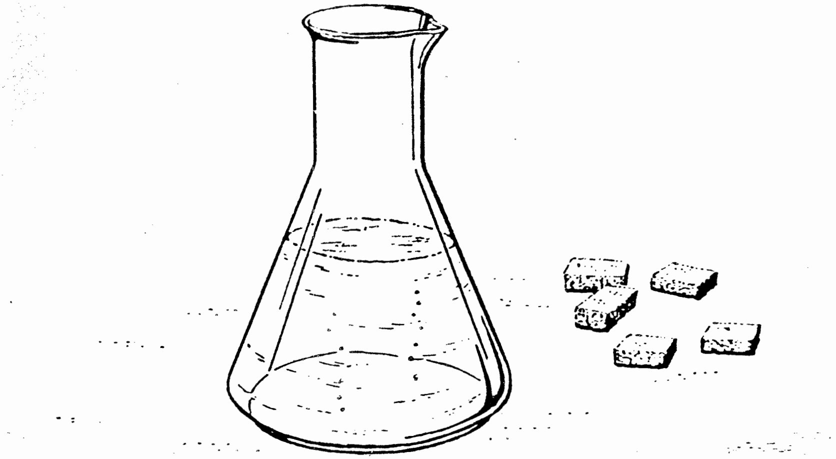


Figure 20

1. What will happen to the volume of water when the cubes of sugar are placed in it?
2. What would happen to the volume and the sugar if the water were warmer or colder?
3. What evidence exists to show there is air in the cubes of sugar?
4. How does the air in the cubes affect the density of the sugar?
5. How does the air in the sugar cube affect its ability to float?

6. How will the volume of the liquid be affected by adding sugar to the beaker?

Teacher's note:

> It is suggested that after the instructor has gone through the questions in the riddle, he ask students how the answers could be determined. The class should then set up experiments to determine these answers. The instructor should ask the class how many times they should repeat their experiments in order to be sure of their answers.

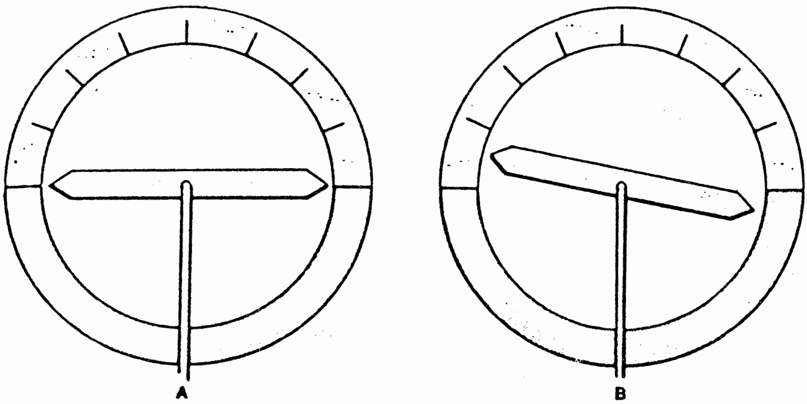


Figure 21 *Dip Needle*

1. The dip needle as shown in Figure 21-A changed during a walk to look like the one in Figure 21-B.
2. What would cause the dip needle on the right to change? In what way has it changed?
3. If the needle dipped even more at some other point, what would you suspect about the earth at that point?
4. If you were going to dig for iron ore, how would you go about selecting a site?
5. Using an airplane and a very sensitive compass-type instrument called a magnetometer, how would you go about mapping a region's magnetic variation?

Teacher's note:

> Involved in this riddle are the concepts of magnetic field, variation in the earth's magnetic field, declination or dip of a magnetic needle, and that such a dip may indicate increased attraction due to deposits

of magnetic types of ores such as iron in the crust. The lesson also develops understanding of the part instruments play in helping scientists study what they cannot sense directly.

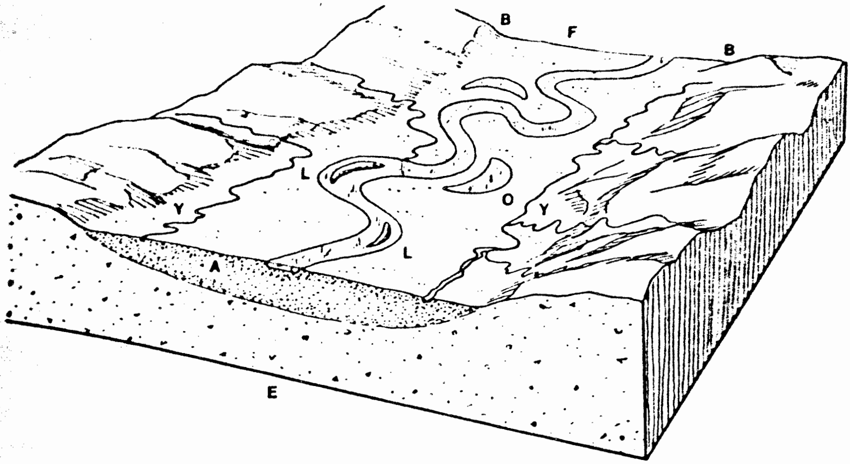


Figure 22 *An Old River*

1. What can you tell about the terrain in Figure 22?
2. Why does the river appear the way it does?
3. How were the moon-shaped objects with water in them formed?
4. What did the valley look like?
5. What do you think will happen to the valley some time in the future?
6. What other questions can you ask?

See Figure 23 on Page 150

1. What caused this type of feature to develop?
2. What will happen to this mountain over millions of years?
3. What if the mountain is rising at the same rate as it is eroding—what will happen?
4. What other questions can you ask?

See Figure 24 on Page 150

1. The tubes shown in Figure 24 have had one yeast cell each added to the solutions they contain. What can you conclude about the solutions?

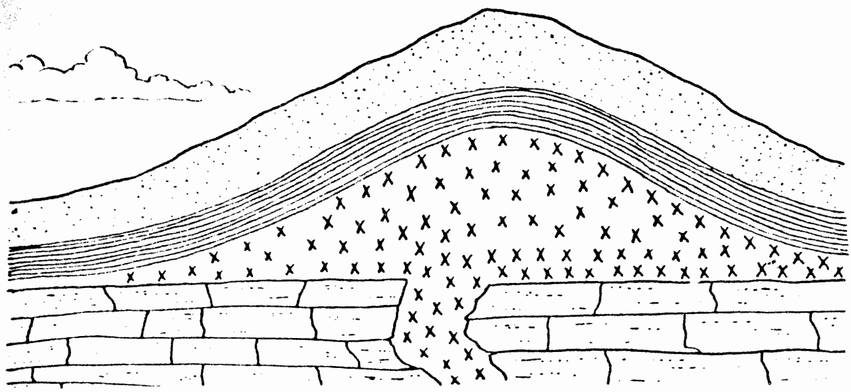


Figure 23 *How Was a Geological Feature Formed?*

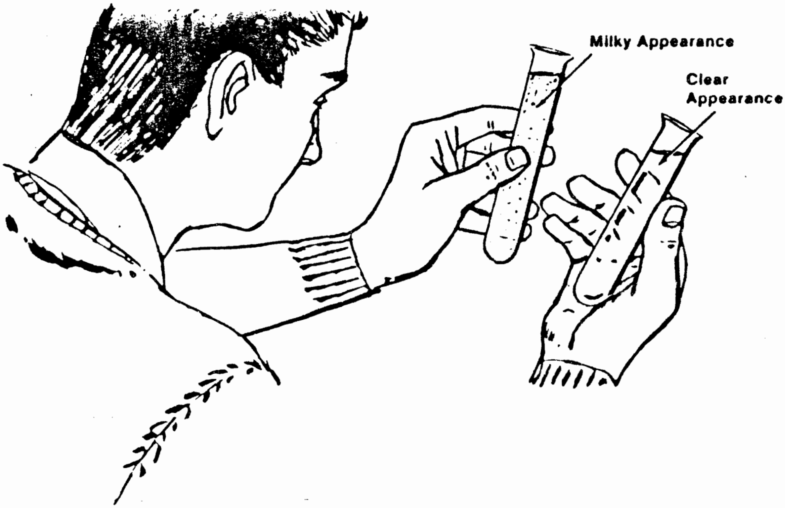
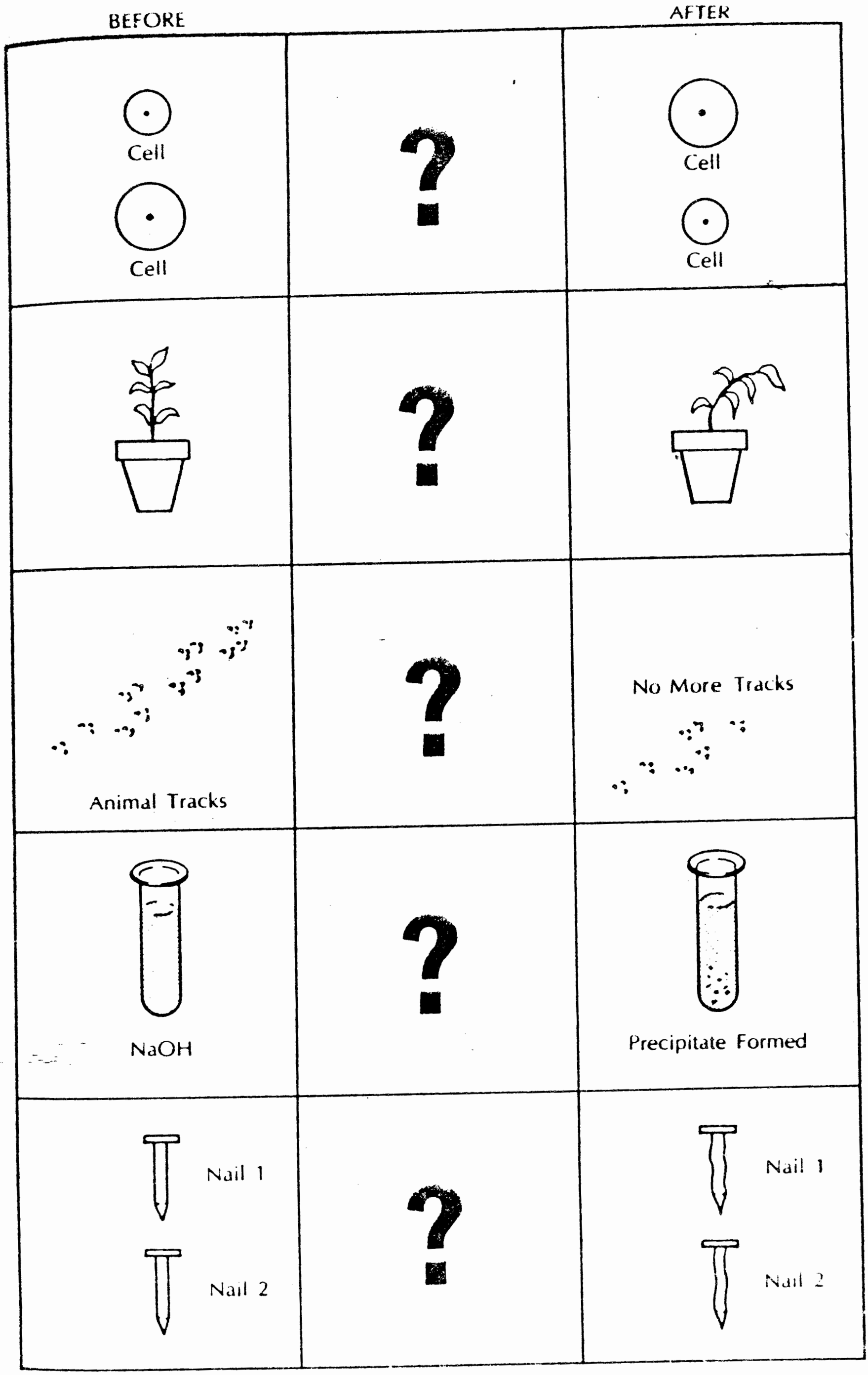


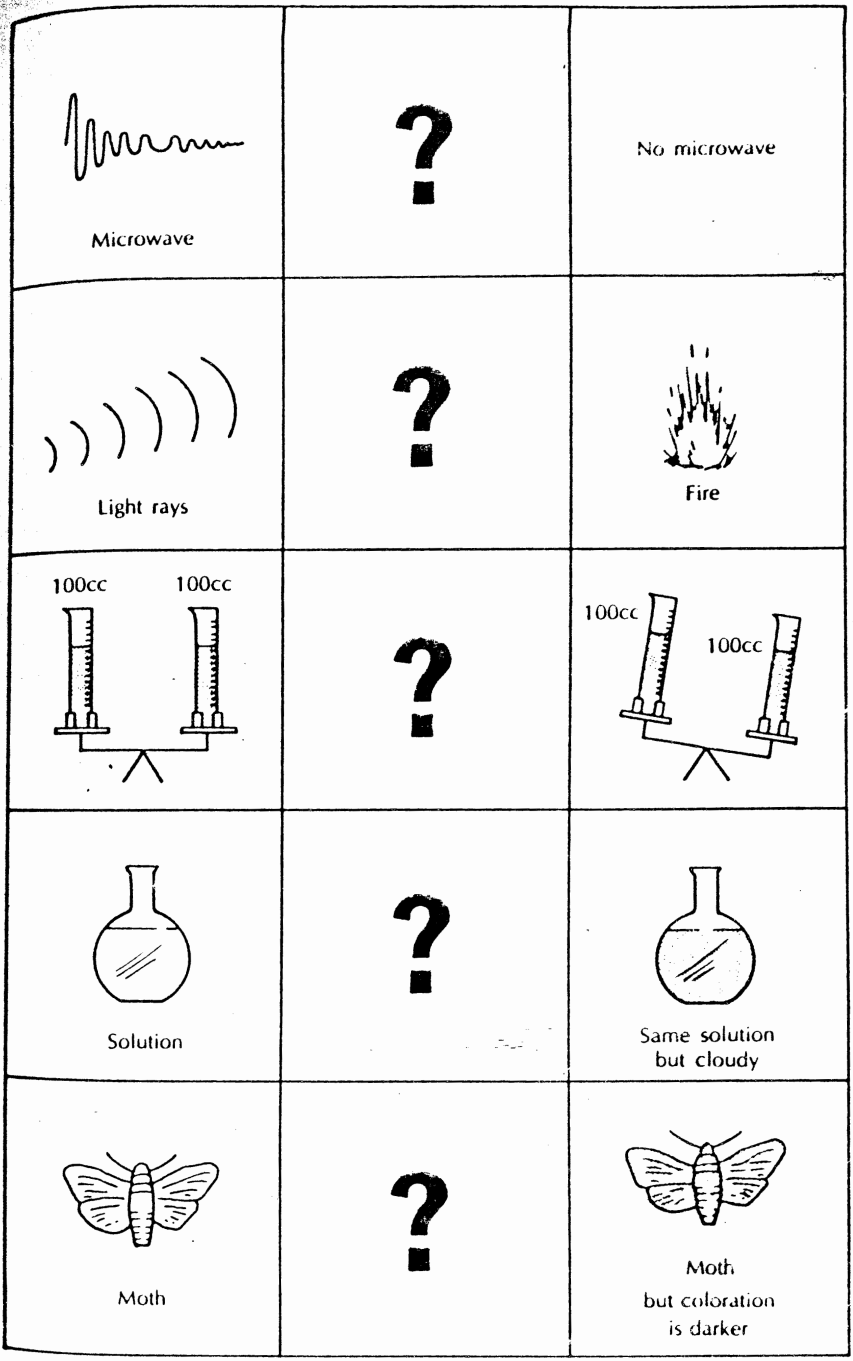
Figure 24

2. What made one of them milky? Why aren't both of the tubes milky? Under what conditions were both of the tubes kept?
3. In the milky tube, what type of food do you suspect is present?
4. What would happen in Figure 24 if you varied the temperature? pH? Amount of light present? Type of food?

5. If conditions were kept the same, what do you think would eventually happen to the milky tube? To the other tube?
6. If you took the clear tube, assuming it contained the same food material, and placed it in the environment where the milky tube was kept, what would happen?
7. If you wanted to clarify the milky tube, what would you do?
8. If you tested the milky tube's solution, what would you expect to find?

A format for a riddle lending itself particularly well to overhead projection is the before and after type of riddle. These present students with a diagram or picture before some factor has been altered and then the students are shown another picture illustrating a situation after modification. The student is to hypothesize what happened in the before situation to reach the modification shown in the after diagram. On pages 152 and 153 are examples of before and after riddles.


BEFORE
AFTER
Cell
Cell
Cell
Cell
?
Animal Tracks
No More Tracks
NaOH
Precipitate Formed
Nail 1
Nail 2
Nail 1
Nail 2


Microwave
?
No microwave
Light rays
?
Fire
100cc
100cc
?
100cc
100cc
Solution
?
Same solution but cloudy
Moth
?
Moth but coloration is darker

Riddles to Show Relationships

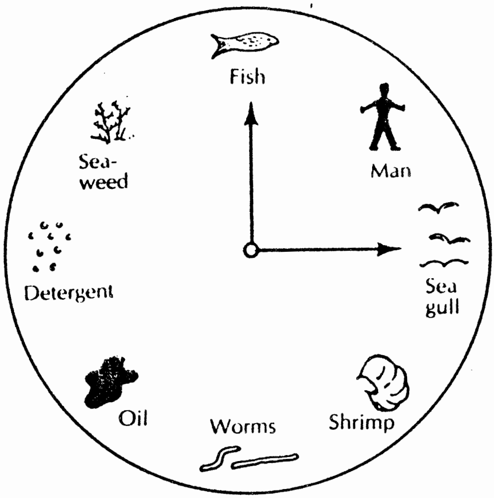


Figure 25

The riddle in Figure 25 is constructed similar to the face of a clock. The arms are turned to different organisms and the class asked what the ecological relationships are between them.

Three-Dimensional Riddles

The techniques of questioning with pictorial riddles can also be used with objects as indicated below:

TYPES OF THREE-DIMENSIONAL RIDDLES

1. Mobiles
2. Spheres, cubes, hexagons, etc., with a series of related pictures pasted on each surface
3. Collages
4. Objects — rocks, organisms that are new to the student, a piece of machinery, unique science apparatus, etc.

Some examples of the questions you might ask with these objects are:

1. What do you think this three-dimensional riddle is about and why?

2. *What particularly strikes you about this riddle?*
3. If you were going to change it, what would you do and why?
4. What does this riddle suggest to you to construct to give the class an impression of you as a person?

Sources to Prepare Riddles

Riddles may be prepared from many different types of materials as indicated below:

1. Photographs, Polaroid 35 mm slides, etc.
2. Magazine pictures
3. Diagrams
4. Cartoons
5. Greeting cards
6. Objects

Case Histories

Another technique to motivate discussion is to use case histories in science. These histories tell stories about the development of some science concepts. The instructor may tell the students part of what was done and then ask what they think was the next step. Case histories can be constructed from a classic experiment in the history of science. The Science Research Associates publish a collection of science case histories for high school.

Covers of Science Magazines

An activity to supplement a science lesson can be constructed around magazine covers depicting various aspects of science. *Science*, the journal of the American Association for the Advancement of Science, has some very interesting covers which lend themselves well to this approach. The instructor holds the cover picture up and asks questions to give students hints about the topic represented.

DISCUSSION AS A TECHNIQUE OF REVIEW

All of the discussion techniques outlined above can be used to good advantage for class review. Discussion may also be used as an excellent review for laboratory work. After an instructor has had a class perform several experiments in a unit in the laboratory, he should take time to discuss what conclusion can be drawn from the laboratory work. Consideration should also be given to how the information was obtained, what types of problem-solving and cognitive behaviors were involved in determining the answers, and with what assurance the students know their information is correct. A discussion of this type can do much to reinforce learning and divide the trivia from the really important aspects of learning.

The One-Word Type of Review

The one-word approach may be used to involve all the students in the review process. After students have read, seen a film, performed a laboratory exercise, or been involved in other types of investigative work, ask them to write in one word their impressions. These words should then be passed to the front of the class and several of them should be written on the board. The students should then be asked to explain why they wrote their words. After they give their explanations, they should then be asked to take any three words and construct a sentence. This technique provides an excellent review of the material while involving all the students in the class.

Learning to Lead a Good Discussion Never Ends

A teacher never quite perfects his ability as a discussion leader, but he should never stop trying to improve this ability. Excellence in discussion comes only with wisdom, not only in subject matter but in learning how to develop talents and self-concepts. To a dedicated teacher there is probably no greater satisfaction than to be able to walk out of class knowing that he has developed the students' mental abilities to the point where his presence is practically unneeded except as an organizer. To acquire this facility requires preparation and constant self-analysis, but it is one of the intellectual satisfactions that come only with good teaching.

SUMMARY

The lecture method should play a relatively minor role in instruction in the secondary schools. Inquiring discussions motivate students and involve them more in cognitive processes than do lectures. There are definite techniques to be used in leading inquiry-oriented discussions. The instructor should mainly question and give little or no information; the type of question asked by the teacher helps students discover the concept or principles involved in the learning situation. To lead a good discussion requires extensive preparation. The leader should know the objectives he wishes to attain, have a series of relevant questions outlined, and spend time at the end of the discussion analyzing how the conclusions were reached. Part of the discussion should be devoted to reflecting on the thought processes used in arriving at the conclusions involved in it. In this way, better understanding and development of the cognitive processes are insured.

A discussion leader should give positive reinforcement as much as possible. He should compliment students on good ideas and suggestions and seldom deride or make sarcastic remarks about poor suggestions. Regardless of the answers given in a discussion, the teacher should try to react positively to the participants; ignoring a response is a poor procedure. Eye contact is important as a motivator and a means of receiving feedback. A good method of starting a discussion is to use a demonstration or overhead projection pertaining to a subject or topic of interest to the student. In leading the discussion, attempt to recall previous comments and interrelate the suggestions with the names of the individuals who made them. Remember that students will occasionally test your judgment to determine your competence as a teacher.

Some special techniques used in stimulating discussion are invitations to inquiry, single-topic films, pictorial riddles, case histories in science, and questions organized around covers of science magazines. All of these can be used to suggest open-ended experiments if students are aware of the factors involved in experimentation. Discussion is also an excellent vehicle for review, both in class and laboratory work. The one-word approach may be used to involve all the students in the review process.

Further Investigation and Study

1. What are the advantages of discussion over lecture?
2. How can a discussion be used as an approach to inquiry?
3. How can you motivate students during a discussion?
4. Choose some topic and outline how you would present it in a discussion.
5. How does an inquiring discussion differ from one used to summarize?
6. What are some things that tend to stifle discussion?
7. What does your attitude have to do with setting the stage for a good discussion?
8. Why do students sometimes test your judgment while you are leading a discussion?
9. How can you indicate that you have good judgment?
10. What should you do when you don't know the answer to a problem?
11. Write an invitation to inquiry and classify the science processes you are requiring in the right margin.
12. How can an invitation to inquiry be used to suggest some open-ended experiments?
13. How is a single-topic film used as a method of inquiry? How does it differ from the traditional film?
14. Prepare a before and after type of riddle.
15. Prepare a three-dimensional type of riddle.
16. Prepare a riddle using a cartoon.
17. Describe an assignment where you would use the "one-word approach."
18. What are case histories and how may they be used?
19. What is the main role of an inquiring discussion leader?

Reality is not a datum, not something given or imposed, but a construction which man makes out of the given material.

José Ortega y Gasset

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Methods of Science Teaching: Inquiry through Demonstrations

In the first-period general science class, Mr. O'Brien took a candle out of a box and placed it on the demonstration desk. He told the class he would show them the difference between a physical and a chemical change. He struck a match and placed the candle over the flame until the wick burned. Soon, some of the wax was melting, dripping, and then solidifying. He said, "This is an example of a physical change. The candle is partially burning and the wax is changed in the process of burning to carbon dioxide and water. This is a chemical change." The students watched the demonstration, and some wrote notes in their notebooks.

Across the hall, Mr. Jackson was teaching the same unit. He also wanted to have students learn about physical and chemical changes. Mr. Jackson was not certain how he was going to do this. He asked Mr. O'Brien if he knew a good demonstration to show these changes. Mr. O'Brien suggested he burn a candle. Mr. Jackson, however, went about teaching these concepts in a different manner. After the bell rang and the students were seated, he took a candle and a match box out of his demonstration desk and placed them on top of the desk and asked, "What am I going to do with the candle and match?"

Art answered, "You are going to light it."

Mr. Jackson replied, "That's right, but what will happen to the match and candle when I light them? How will they vary? What will happen to the candle when it burns? Will it drip?"

Several students raised their hands and suggested answers to his questions. He lit the candle and it started to drip. He asked, "Why does the candle drip? What will happen if we try to burn the dripped material? Where did the dripped material come from, and how did it change while the candle was burning?"

George explained that the material only melted and then solidified. Mr. Jackson asked the rest of the class what they thought of George's explanation, "What evidence was there for his suggestion?"

Several members of the class discussed the matter and agreed that this material had only changed form in the process of melting and resolidifying.

Mr. Jackson asked, "What is this type of change called?"

Two students raised their hands and suggested that it might be a physical change.

Mr. Jackson then proceeded in a similar manner to ask about what was happening to the candle as it burned. What caused it to get shorter, and why would it eventually have to be replaced? The class discussed this matter and eventually discovered that the candle was also changing chemically.

Which of the above teaching methods do you think would be the more effective way to demonstrate physical and chemical changes and why? What did students learn from Mr. Jackson's approach that they might not have learned from Mr. O'Brien's? Which of the above methods stressed the inquiry approach and why? Which method do you think took instructors more time to prepare? Which would be more inductive in its approach? Why do you think teachers have traditionally emphasized the deductive method in giving demonstrations? If you were going to teach this lesson, how would you do it better?

A demonstration has been defined as the process of showing something to another person or group. Clearly, there are several ways things can be shown. You can hold up an object such as a piece of sulfur and say, "This is sulfur"; or you can state, "Sulfur burns, light some sulfur, and show that it burns." Showing in this way mainly involves observation or verification. Mr. O'Brien's use of a demonstration was of this type.

A demonstration can also be given inductively by the instructor's asking several questions but seldom giving any answers. An inductive demonstration has the advantage of stressing inquiry. This encourages students to analyze and make hypotheses based upon their knowledge.

Their motivation is high because they like being confronted with riddles, and in an inductive demonstration they are constantly confronted with riddles. The strength of this motivation becomes apparent when one considers the popularity of TV quiz programs over the last twenty years. Inviting students to inquire why something occurs taxes their minds and requires them to think. Thinking is an active mental process. The only way students learn to think is by having opportunities to do so. An inductive demonstration provides this opportunity because the answers the students give to the instructor's questions act as "feedback." The teacher has a better understanding of the students' comprehension of the demonstration. The feedback acts as a guide for further questioning by him until the students discover the concepts and principles involved in the demonstration and the teacher is sure they know its meaning and purpose.

Demonstrations, in addition to serving as simple observations of material and verification of a process, may also be experimental in nature. A demonstration is an experiment if it involves a problem the solution to which is not immediately apparent to the class. Students particularly like experimental demonstrations because they usually have more action. Students enjoy action, not words! They love to watch something happening before their eyes.

DEMONSTRATIONS VERSUS INDIVIDUAL EXPERIMENTATION

Educators have stressed the importance of self-instruction with less reliance on large-group or class instruction. Education should be preparation for life, and part of that preparation must be to insure that the individual continues his education long after formal education ends. It is important that the school reinforce habits and patterns of learning which will prepare the individual to continue his education many years after he leaves organized instruction. Laboratory work, because it involves the individual directly in the learning process as well as imparting working skills, is thought to be superior to giving a demonstration. A person working on a laboratory problem has learned far more than just the answer to the problem. He may learn to be efficient, self-reliant, and analytical; to observe, manipulate, measure, and reason; to use apparatus; and, most importantly, to learn on his own. Individual laboratory experimentation helps to facilitate the attainment of these goals better than demonstrations do. For this reason *demonstrations should play a minor role* in science instruction, with individual student investigation receiving top priority.

Demonstrations are only justified for the following reasons:

1. Lower cost. Less equipment and fewer materials are needed by an instructor doing a demonstration. This is, therefore, cheaper than having the entire class perform experiments. However, it should be remembered that cheap education is not necessarily better education.
2. Availability of equipment. Certain demonstrations require equipment not available in sufficient numbers for all students to use. For example, not every student in a physics class needs to have an oscilloscope to study sound waves.
3. Economy of time. Often the time required to set up equipment for a laboratory exercise cannot be justified for the educational value received. A teacher can set up the demonstration and use the rest of the time for other instruction.
4. Less hazard from dangerous materials. A teacher may more safely handle dangerous chemicals or apparatus requiring sophisticated skills.
5. Direction of the thinking process. In a demonstration, a teacher has a better indication of the students' thinking processes and can do much to stimulate the students to be more analytical and synthetic in their reasoning.
6. Show the use of equipment. An instructor may want to show the students how to use and prevent damage to a microscope, balance, oscilloscope, etc.

REASONS FOR DEMONSTRATING
1. Costly Materials
2. Insufficient Equipment
3. Hazards
4. Economy of Time
5. Stimulate Thinking
6. Show the use of Equipment

TECHNIQUES OF PLANNING AND GIVING A DEMONSTRATION

To plan an efficient and effective demonstration requires extensive organization and consideration of the following points:

1. The first step is to list the concepts and principles you wish to teach. Direct the design of the entire demonstration to the attainment of these.
2. If the principle you wish to teach is complex, break it down into concepts and give several examples for each concept. For example: Photosynthesis involves understanding concepts of radiant energy, chlorophyll, carbon dioxide, glucose, water, temperature, a chemical change, and gases. A student's memorizing that green plants can make sugar in light with water results in little understanding if he does not know the meaning of the concepts listed above.
3. Choose an activity that will show the concepts you wish to teach. Consult the following sources for possible suggestions for activities:

Middle School Level

Sund, Robert B.; Tillery, Bill W.; Trowbridge, Leslie W. *Elementary Science Discovery Lessons—The Earth Sciences*. Boston: Allyn and Bacon, 1970.

Sund, Robert B.; Tillery, Bill W.; Trowbridge, Leslie W. *Elementary Science Discovery Lessons—The Physical Sciences*. Boston: Allyn and Bacon, 1970.

Sund, Robert B.; Tillery, Bill W.; Trowbridge, Leslie W. *Elementary Science Discovery Lessons—The Biological Sciences*. Boston: Allyn and Bacon, 1970.

Hone, E.; Joseph A.; *et al. A Sourcebook for Elementary Science*. New York: Harcourt Brace Jovanovich, 1971.

Middle and Secondary School Level

Joseph, A.; Brandwein, P.; *et al. A Sourcebook for the Physical Sciences*. New York: Harcourt Brace Jovanovich, 1961.

Morholt, E.; Brandwein, P.; and Joseph, A. *A Sourcebook for the Biological Sciences*. New York: Harcourt Brace Jovanovich, 1966.

Bureau of Secondary Curriculum Development, New York State Education Department. *The General Science Handbooks, Part I, II, and III.* Albany, 1961.

United Nations Educational, Scientific and Cultural Organization. *UNESCO Sourcebook for Science Teaching*. Paris, 1956.

Heller, R. *Geology and Earth Sciences Sourcebook for Elementary and Secondary Schools*. (Prepared under guidance of the American Geological Institute.) New York: Holt, Rinehart and Winston, 1962.

Other Sourcebooks in Biology

Feldman, S. *Techniques and Investigations in the Life Sciences*. New York: Holt, Rinehart and Winston, 1962.

Lawson, C., and Paulson, R.E. *Laboratory and Field Studies in Biology, A Sourcebook for Secondary Schools*. New York: Holt, Rinehart and Winston, 1960.

Miller, David, and Blaydes, Glenn. *Methods and Materials for Teaching the Biological Sciences*. New York: McGraw-Hill Book Co., 1962.

4. Design the activity so each student becomes involved as much as possible.
5. Gather and assemble the necessary equipment.
6. Go through the demonstration at least once before class begins.
7. Outline the questions you will ask during the demonstration. This is especially important in doing an inquiry-oriented demonstration.
8. Consider how you will use visual aids, especially the overhead projector, to supplement the purpose of the demonstration.
9. Decide on the evaluation technique to use.
   A. Written techniques
      1. Essay—a. Have students take notes and record data during the demonstration.
         b. Have them write a summary of the demonstration.
      2. Quiz—Have students write answers to questions or prepare diagrams to see whether they really understood the purpose of the demonstration. Stress application of principles.
   B. Verbal techniques
      1. Ask students to summarize the purpose of the demonstration.
      2. Ask for applications of the principles they have learned by giving them problems in which they will have to apply these principles.
10. Consider the time a demonstration will take. Try to move it rapidly enough to keep students attentive. Prolonged or complicated demonstrations are generally undesirable because they don't hold the students' interest.

11. When you plan a demonstration, do it well, with the intention that you will probably use it for several years. This helps to lessen your preparation in future years. Evaluate a demonstration immediately after giving it to determine the weaknesses and strengths of the presentation. Add any questions which will contribute to the inquiry presentation when you use the demonstration again. The next time you give it, it will require only a few moments preparation.

Examples of Student-Centered Inquiry Demonstration

Reproduced below is a plan for an inquiry demonstration lesson. Notice the application of the above suggested format in constructing the lesson.

FORMAT FOR DEMONSTRATION LESSON

1. List concepts and principles.
2. Devise activities to discover these.
3. Write suggested questions to help students discover these.
4. Evaluate how well students achieved objectives and the science processes.

DEMONSTRATION LESSON—AIR PRESSURE

Concepts and Principles

Air exerts pressure.

A partial vacuum occurs when air is evacuated from a container.

Student-Involved Activities

Critical thinking processes required by the questions:	
	1. Set up a vacuum pump with a bell jar containing a partially inflated balloon.
Hypothesizing	2. Ask: What do you think I am going to do with this apparatus?
Hypothesizing	Why is the balloon inside the jar?
Inferring	How will the air be evacuated from the bell jar?
Hypothesizing	What will happen to the pressure inside the jar as it is evacuated?

Hypothesizing	What will happen to the balloon as the pressure around it is decreased.
Designing an experiment	If you were going to measure how the pressure varies inside the bell jar as it is evacuated, what would you do?
	3. Evacuate the chamber by turning on the pump.
Observing	4. Ask: What do you observe?
Designing an experiment	5. Group yourselves into teams of five students. Come up with a method of how you would accurately measure the expansion of the balloon inside the evacuated chamber.
Designing an experiment	How would you determine the ultimate expansion possible for a balloon?
Observation	6. Let each group test out its ideas for determining the amount of expansion.
Recording date	7. Each group should record its data and place it on the chalk board.
Inferring	8. Ask: Which group had the best method and was the most accurate?

Evaluation

Summarizing	1. What did you get out of being involved in this demonstration?
Summarizing	2. How does a vacuum pump work?
Hypothesizing	3. What would happen to the balloon if it were placed under a bell jar ten times larger than the one in class and the jar were evacuated?
Inferring	4. Why does the balloon expand as the bell jar is evacuated?
	5. Diagram below what you think happens to the gas inside the balloon as it expands.
Inferring	6. Why do astronauts wear such complicated suits?
Hypothesizing and applying	7. What would happen to an astronaut if he ripped his suit on the moon? Why?

Review the above lesson again. How would you go about making it a better lesson? What purpose does the writing of the science processes in the margin serve in insuring the preparation of a good lesson? How would you start this lesson in a novel way to involve all the students?

AWARENESS IN GIVING A DEMONSTRATION

DEMONSTRATIONS SHOULD:
1. Be Visible
2. Be Audible
3. Be Novel and Exciting
4. Be Inquiry Oriented
5. Allow for Wait-Time

The following are suggestions for giving a demonstration:

1. Make it easily visible. If you are working with small things, can you use an overhead projector to make them more visible?
2. Speak loudly enough to be heard in the back of the room. Do you speak loudly enough and fluctuate the tone and volume of your voice to avoid monotonous delivery? When a student responds do you ask him to speak up so other students can hear? Do you repeat questions and answers of students for emphasis and audibility?
3. Do you display zest in giving the demonstration? Are you excited with the demonstration? Do you make it come alive? A good demonstrator is somewhat of a "ham." He uses dramatic techniques to excite and involve his students. The way in which a teacher makes a demonstration come alive is as much an art as is reading Shakespeare well to an enraptured audience.
4. How do you stage the demonstration? How do you start it to involve everyone immediately? One suggestion is to place unique objects on a demonstration desk. For example, a transfusion container or a Van de Graff generator placed on a desk does much to motivate students' inquisitive minds. Before you even begin, you have the students with you, wondering what you are going to do.

   a. Teach inductively. Start your demonstration with a question. If you have interesting equipment, ask your students what they think you are going to do with the equipment. Spend some time just questioning about the apparatus. In the construction of a transfusion container, for example, there are several scientific principles involved, such as: partial vacuum, air pressure, sterile conditions, nutrient for the cells placed in the bottle, and anticoagulants to prevent clotting of the blood.

b. Ask questions constantly about what you are going to do, what's happening, why they think it is happening, and what the demonstration is proving or illustrating.

c. Know the purpose of what you are demonstrating. Use the questions you devised only as a guide. The questions you have anticipated may be excellent, but also be ready to pick up suggestions from the questions students ask during the time they are observing the demonstration.

d. Give positive reinforcement. Always recognize a reply: "Say, I think you have something there." "Good, you're thinking." "What do the rest of you think of John's remarks?" When a student gives a good explanation, compliment him. Seldom act negatively to a student's answer. Don't say, "That's wrong." Rather say, "It's good you're thinking, but your answer is not quite right."

5. Allow at least three seconds for students to reply to your questions. This wait-time is important for the students to think and reason about the demonstration.

6. Use the blackboard to describe the purpose of the demonstration. Verbal explanations are seldom enough. Any picture or diagram you make on the board immediately attracts the students' attention. Remember that your students have lived in a TV-centered environment; as soon as they see a visual representation on the board they are drawn to it. A beginning teacher often fails to realize or even consider how the blackboard can complement the learning activity.

7. At the conclusion of the demonstration have a student summarize what has occurred in the demonstration and its purpose. This helps to fix the purpose of the demonstration in the minds of the students.

8. Evaluate your lesson—orally or in a written summary.

WAYS TO PRESENT A DEMONSTRATION

TYPES OF DEMONSTRATORS

1. Teacher
2. Teacher Student
3. Student Group
4. Student
5. Guest

There are several ways in which a demonstration can be given. A teacher-centered demonstration is seldom the best way because it does not involve students enough. When students participate actively in giving a demonstration they are more interested and, consequently, learn more. There are five ways in which a demonstration can be presented. They are:

1. *Teacher demonstration.* The teacher prepares and gives the demonstration by himself. This approach has the advantage usually of better organization and more sophisticated presentation.

2. *Teacher-student demonstration.* This is a team approach in which the student assists the teacher. This type of demonstration gives recognition to the student. The class may be more attentive because they like to watch one of their peers perform.

3. *Student group demonstration.* This can be used on occasion; it has the advantage of more actively involving students in the presentation.

The group approach can be used to advantage if students are allowed to select the individuals in their group. The teacher should evaluate the group as a whole and assign the group a grade which is the same for each of its members. The groups will form at first along friendship lines. If, however, some of the members of the group are not productive they will be rejected the next time groups are selected. The peer pressure to produce and become actively involved in the activity replaces the necessity for a teacher to encourage students to work. This group arrangement may also be effective in organizing laboratory work. The only problem is that the teacher initially has to be patient until the group pressures are brought to bear upon the nonproductive students in the class.

4. *Individual student demonstration.* This can be a very effective demonstration, especially if the student giving the demonstration has high status among his peers. An effective way to have individual student demonstrations is to have upperclassmen come in from advanced science classes and present demonstrations to the lowerclassmen. A freshman general science class may become enthralled when a physics or chemistry senior comes into their class to give a demonstration. An upperclass student excited about giving a demonstration helps to convey that excitement to the students in the class.

5. *Guest demonstration.* Guest demonstrators can do much to relieve a boring pattern of routine class activities. Other science teachers in the school may be called in to present a demonstration or activity in which they have some special competence. Professional scientists are often willing to give special demonstrations. In certain parts of our country, scientific societies and industries have established groups which present

exciting science demonstrations to schools. The Southern California Industry-Education Council and the Greater Washington Council are but two of these groups.

What are the advantages of student demonstrations?

Courtesy of Bob Waters, University of Northern Colorado

Silent Demonstration

Dr. Obourn of the U.S. Office of Education has recently stressed the importance and desirability of the silent demonstration. In the passage below he compares the teacher-talking demonstrations with silent demonstrations.

> The usual kind of demonstration by which science teachers give their students visual or auditory experiences is the teacher-talking demonstration. In this performance the teacher is actor and commentator. The pupils, who are supposed to be learning from the new experience how to attack a difficulty or develop a concept, are spectators. But they do not necessarily learn scientific facts or principles from a demonstration in which everything is done for them. Pupils really learn when they observe and react to what is presented.
>
> There is a kind of demonstration that is likely to ensure, on the part of the student, careful observation, accurate recording of data, and

practical application, later, of the ideas gained from the experience. This procedure is the *silent demonstration*. The following comparison of the two kinds of demonstrations shows how they differ.

Teacher-Talking Demonstrations	*Silent Demonstration*
Teacher states purposes of the demonstration.	Pupil must discover purpose as the demonstration progresses.
Teacher names pieces of apparatus and describes arrangement.	Teacher uses apparatus. Pupils observe equipment and arrangement.
Teacher is manipulator and technician, tells what is being done, points out and usually explains results.	Teacher performs experiment. Pupils observe what is being done and then describe results.
Teacher often points out the things which should have happened and accounts for unexpected results.	Pupils record results as observed. Teacher checks for accuracy and honesty in reporting. Teacher repeats the experiment if necessary.
Teacher summarizes the results and states the conclusions to be drawn. Pupils usually copy the conclusions as stated.	Pupils summarize data and draw their own conclusions based on what they observed. Teacher checks conclusions and repeats experiment if necessary.
Teacher explains the importance of the experiment and tells how it is applied in everyday life.	Pupils attempt to answer application questions related to the demonstration.

The silent demonstration, since it cannot be supplemented or strengthened by explanation, requires more careful planning than does the teacher-talking demonstration. In preparing the silent demonstration, the teacher may find this general procedure a good one:

1. Fix clearly in mind the object of the demonstration.
2. Select the apparatus and materials best suited for the demonstration.
3. Determine the beginning point of the demonstration. The beginning is based upon what the teacher assumes that the pupils know.
4. Analyze the difficulty into steps of learning. Perform the parts of the demonstration to meet these difficulties.

5. Perform the techniques so that they may be observed in all parts of the room. The steps should follow some order in relation to the steps of learning.
6. Give pupils an outline of the steps to be used. Mimeographed outlines may be used, or an outline may be put on the blackboard.

The following procedure will illustrate how a silent demonstration may be carried out. The difficulty to be solved is:

"Why does water circulate when it is heated, or what causes convection currents?" The teacher assumes that the pupils know how to weigh, and how to read thermometers.

The Teacher Does	*The Pupils See*
1. Fills with water two flasks of the same size. Fits each flask with a one-hole stopper and a glass tube about ten inches long. (The water should rise in the tubes when the stoppers are forced into the flasks.) Heats one flask. Cools other flask in ice water. Lets both flasks return to room temperature.	The controls—flasks of the same size, tubes of the same size, the same volume of water in each flask. Water moving up the glass tube when it is heated. Water moving down the glass tube when it is cooled. (If the temperature of the water should go below 4°C., it would begin to expand.)
2. Places two 250 cc. graduates on scale pans of a balance. Places balance in equilibrium. Fills one graduate to the 250 cc. mark with cold water, the other to the same mark with hot water.	The apparatus and its arrangement. The same volume of water used in both graduates. Cold water overbalancing the hot water.
3. Fills a large beaker with water nearly to the top. Places beaker on tripod. Places Bunsen burner underneath and near one side. Suspends four thermometers in water, one near bottom, one at top of water above burner, and two on opposite side in similar positions. (Thermometers whose readings are not more than one-half degree apart must be used.)	The apparatus and its arrangement. The readings on the thermometers. (If the water is heated gradually, the changes in temperature may be noted from time to time.)

4. Adds fine pieces of sawdust or a crystal or two of potassium permanganate to the water in the beaker (see 3 above). Continues to heat.

The change in arrangement. Material rising above the place where heat is applied, crossing over the top, going down near the opposite side and across the bottom toward the burner.

5. Asks pupils to consider what they have observed and to draw their own conclusions.

(Since each pupil draws his own conclusions, the wording will differ, but the main ideas are likely to be the same.)

General Conclusions Based on Observed Data

Water expands when heated and contracts when cooled.

Warm water is less dense than cold water. If water expands when heated, and the total weight remains the same, then the volume of a unit of warm water must be lighter than the volume of an equal unit of cold water.

If water is heated in a container, the warm water moves toward the top and the colder water toward the bottom. The water circulates until all of it becomes heated.

Water circulates because its density is changed when it is heated.

6. Asks pupils to use their general ideas in explaining such applications as the hot-water heater, the hot-water heating system, and the like.

(Each pupil formulates his own explanation and submits it for examination by teacher and fellow-pupils.)[1]

Silent demonstrations should not be used frequently because there is no way the teacher can determine whether the students are reaching the objectives while the demonstration is being given. Silent demonstrations can, however, provide a welcome change in the routine activity of the class. They can be used effectively, provided an instructor accentuates his movements in the demonstration so the students can see and have some hints about what is relevant. In a silent demonstration, *visibility* is extremely important and must be insured; otherwise, the students will quickly become frustrated, leading eventually to discipline trouble.

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[1] E. S. Obourn, *Aids for Teaching Science Observation — Basis for Effective Science Learning*, Office of Education Publication No. 29024 (Washington, D.C.: U.S. Government Printing Office, January, 1961).

EQUIPMENT AND STORAGE OF DEMONSTRATION EQUIPMENT

Equipment made by you or your students can lend an added fascination to a science demonstration because students are often more impressed by homemade equipment. Parents, industrial companies, and students often can construct or provide apparatus for the school without cost. Having students build equipment involves them in improving the science instruction of the school. This personal investment helps to build student morale and to show the community that the science department is an active and dynamic part of their school.

Considerable thought should be given to storing equipment after use so it may be found easily in the future and set up again with little effort. One way to do this is to establish a list of headings under which to store materials. For example, in physics, storage areas might be labeled: "electricity," "magnetism," "heat," "light," "sound," "atomic structure," etc. In biology, storage categories might be: "glassware," "chemicals," "slides," "preserved plant and animal specimens," etc. The next time you wish to find the equipment, it can easily be located under the proper storage title. Such a system also makes it easy for students to assist you in storing or obtaining equipment for use in demonstrations.

An efficient way to store small demonstration materials for future use is to obtain several shoe boxes. Place all of the materials you need for a demonstration in the box and label the end of the box. For example, a box might be labeled "electrostatic demonstration materials." You might also include in the box a sheet of paper describing the demonstration. This procedure helps you lessen next year's preparation time when you want to give the same demonstration. A student laboratory assistant can get the box down, read the included sheet describing the demonstration, check to see if all of the equipment needed is present, and replenish needed supplies. The box then will be ready for use, and practically no preparation time will be required of you. This storage

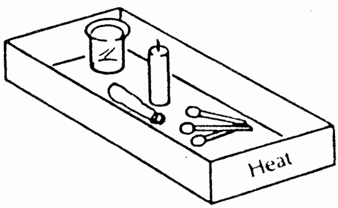


Figure 26

procedure works particularly well with general science materials and simple physical materials. It has a drawback in that when many materials and articles of equipment are stored in the boxes they are not then easily available for other demonstration work during the year.

Special Equipment

Free Sources of Equipment. Science courses often require special science equipment. Some of this specialized equipment may be available to the teacher without cost if he goes through the proper channels. For example, the West Coast Electronic Manufacturers' Association will provide electronic components to science teachers without cost in the San Francisco Bay region. In other areas of the country, there are various companies which will donate materials to the schools upon receiving a written request from the teacher. Consult with experienced teachers or professional scientists in your community to find what is available.

Overhead Projector. Every science class should have an overhead projector with suitable transparency supplies. An overhead projector can become a valuable teaching aid for giving a demonstration or discussion. For example, in biology, a teacher may want to show how to make a wet-mount slide. This cannot be demonstrated easily except by using an overhead projector. Many of the properties of magnetism can be demonstrated well by the use of such a projector.

Microprojector, Video Tape Recorder, and Amplifiers. Another special piece of equipment of particular value to biology classes is the microprojector to project slide material. The advantage of this projector is that the teacher and the student view simultaneously the same material. These microprojectors cost over $2,000 and are beyond the reach of most schools. An alternative to the use of the microprojector is a closed-circuit television camera adapted for use over a microscope; the students view the material on a television console. Amplifiers can be used to good advantage to study heart beats of various animals and to let the class hear them. Some teachers have a small tape library which may contain information that can be used as an actual part of a demonstration. In the study of sound in general science or physics, tape recorders can be put to good use.

A DEMONSTRATION SHOULD STRESS THE HIGHER LEVELS OF LEARNING

A demonstration should contribute to the objectives of the course and school. It should be used to stimulate critical thinking and offer opportunities for manifesting creativity. A demonstration may further be used to develop understanding of the philosophical basis of science. For example, the instructor may ask:

How certain are we of our data?

What evidence is there of certainty in science?

How do scientists fractionate knowledge in order to find answers to bigger problems?

How are the fractional bits of knowledge related to the whole?

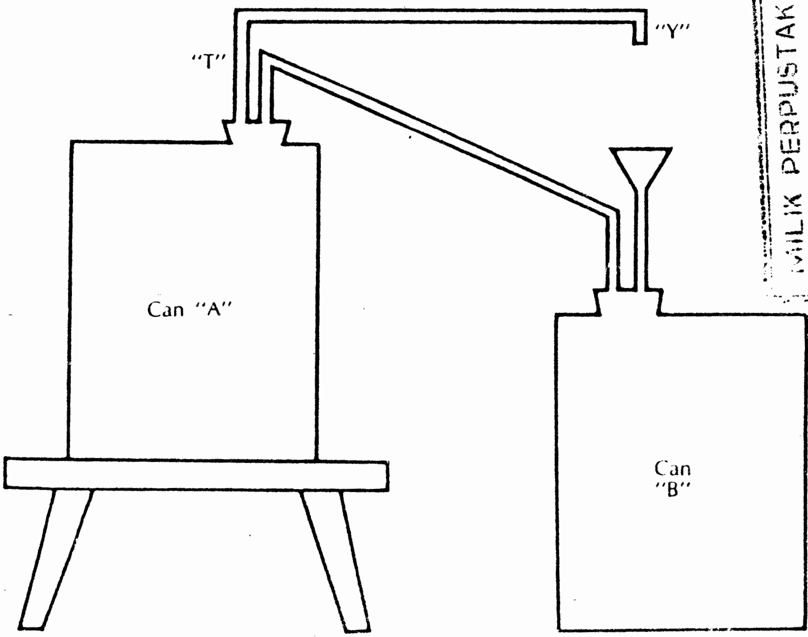
I have just produced chlorine. Chlorine is a poisonous gas. What are the social implications of this fact?

When is a scientist moral, immoral, or amoral?

Questions of this type can be used discriminately throughout a series of demonstrations to build a philosophical awareness of the foundations of modern science. The responsibility to impart knowledge of this sort offers great challenge to the teacher in formulating lessons.

A demonstration technique which embodies higher understanding, more students' individuality, and creative reactions is shown following.

DIAGRAM 1



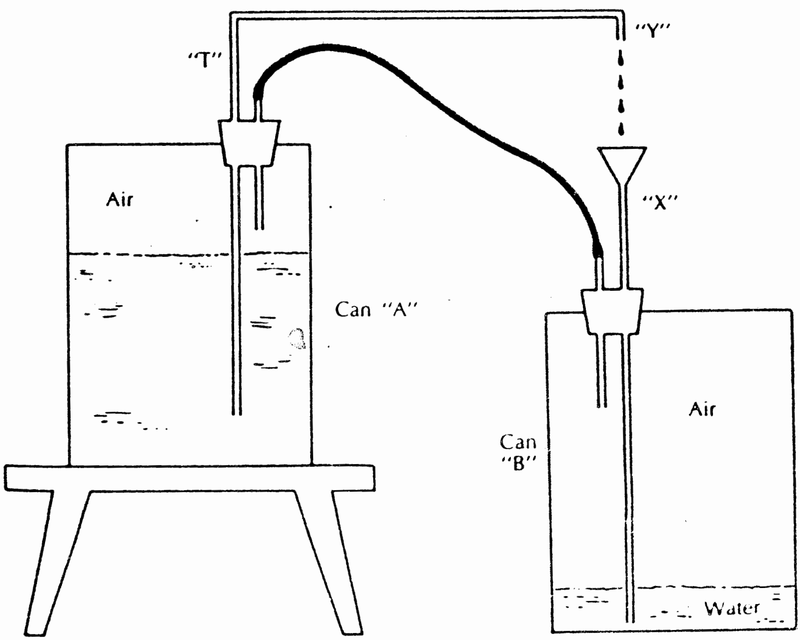
EVALUATION OF STUDENT UNDERSTANDING OF A BASIC PHYSICAL PRINCIPLE

Each student is to be given a Mimeographed sheet containing the information that follows:

Part I

1. The demonstration material is set up as indicated in Diagram 2 below. A beaker of water is filled, and when the instructor is ready to start the demonstration, he pours water into the thistle tube labeled "X." This will start the water flowing from tube "Y."
2. The students are next given a mimeographed sheet resembling Diagram 1 and asked to fill in what they think the apparatus looks like within the can.
3. In a few sentences, they are to explain why the water started to run and why it continues.
4. They are also asked to write what basic principles are involved in the demonstration and how long they think the water will continue to run.

DIAGRAM 2



Part II

After students have completed answering the questions above, they are given a copy of Diagram 2 and asked to take the following test. They are to assume (1) that can "A" and can "B" are identical, (2) that all parts of the apparatus remain unchanged unless a change is specified in the statement they are answering.

Directions:

The liquid would:

In the blank to the right of each statement place an (X) in the column indicating the effect which the given change would have upon the rate of flow. How would the rate at which the liquid flows from the glass tube be affected if:	Not Flow	Flow Slower	Flow at Same Rate	Flow Faster
1. The top of the funnel was only one half as far above can "B" as it was in the diagram?				
2. Can "B" was lowered until the top of can "B" was level with the bottom of can "A"?				
3. The glass tube "T" was lengthened so that it extended twice as far above can "A"?				
4. The funnel was replaced by a thistle tube extending to the same height above can "B" but having a bulb volume three times as great?				
5. The tip "Y" of the glass tube from which the water is flowing was lengthened until it was level with the top of the funnel?				
6. Kerosene, which is less dense than water, was used instead of water? (Neglect differences in viscosity and vapor pressure.)				
7. The volume of can "B" was doubled while its height "H" remained constant?				
8. The bottom of can "A" and can "B" were at the same level?				

The liquid would:

	Not Flow	Flow Slower	Flow at Same Rate	Flow Faster
9. The funnel tube was cut off at "X" and did not extend below the stopper in can "B"?				
10. The glass tube in can "B" to which the hose is fastened was extended to the bottom of the can?[2]				

Part III

After students have marked individually their papers, the instructor discusses with the class their answers. What types of process thinking are required in this type of demonstration?

SUMMARY

A demonstration has been defined as showing something to a person or group. The techniques of planning a demonstration involve determining the concepts and principles to be taught, deciding on activities, gathering the materials, practicing the demonstration, outlining the questions to be asked, and deciding on what evaluational methods to use.

Plan a demonstration with the intention of using it again. A teacher, in giving a demonstration, should be aware of visibility, audibility, and all the aspects which go with good staging. He should have zest, present the demonstration inductively, ask inquiry-oriented questions, give positive reinforcement, use the blackboard or projection techniques, summarize, and evaluate the demonstration. A demonstration may be carried out by the teacher, by the teacher and students together, by a group of students, by an individual student, or by a guest. More attention should be given to demonstrations other than those presented by the teacher, with accompanying comments. Silent demonstrations offer a different approach and emphasize observational techniques.

Equipment should be stored so that it is easily located for future times when the demonstration will be given again. Special equipment often can be secured from local industries without cost. The overhead

[2]This demonstration and evaluation guide was prepared by Dr. Gene F. Craven, Department of Science Education, Oregon State University, Corvallis.

As a teacher how would you build on this experience?
Courtesy of Environmental Studies, Boulder, Colorado

projector and microprojector are excellent teaching aids for giving certain demonstrations.

Individual experimentation generally is more desirable as a teaching technique than are demonstrations, but demonstrations have the advantage of economy of time and money and allow for greater direction by the teacher and provide certain safety precautions. Demonstrations should contribute to the higher levels of learning—those requiring critical thinking and creativity.

Further Investigation and Study

1. Suppose that you wanted to teach the molecular theory of matter. How would you start your unit? What demonstrations would you do and why?
2. What does the word *demonstration* mean?
3. How does an experimental demonstration differ from a verification one?
4. What are the advantages and disadvantages in giving a demonstration?
5. How is the staging of a theatrical production similar to the staging of a demonstration? What considerations have to be made in preparation for both?
6. What can you do to determine whether you are moving through a demonstration at the right rate?
7. What advantages are there to a student demonstration?
8. How would you give a silent demonstration?
9. What are the advantages and disadvantages of demonstrations compared to student laboratory work?
10. Explain how you would give a demonstration to insure that higher levels of learning would be required.
11. How would you store demonstration equipment so that you would be able to use it with greater efficiency?
12. Two chemistry teachers were talking. One said, "I never answer questions." How could the teacher do this and still be a good teacher?
13. How do you feel about your competency now in giving a demonstration compared to your ideas before reading this chapter? Why?

*A student does not learn to "learn for himself" merely by being told to do so. Hence the enquiring classroom is one in which the questions asked are not designed primarily to discover whether the student knows the answer but to exemplify to the student the sorts of questions he must ask of the materials he studies and how to find the answers.**

Joseph J. Schwab

9

Methods of Science Teaching: Inquiry through Laboratory Work

It has often been said that science is not really science unless it is accompanied by experimentation and laboratory work. In the secondary schools in recent years, there has been a resurgence of interest in the laboratory as the focal point for the study of science. It is worth noting that this is not the first time in the history of science education in the United States that the laboratory has come into prominence. The late 1800s saw the construction of laboratories in secondary schools and colleges with a corresponding change in emphasis in the methods of instruction in the sciences. The recitation method and the catechetical approach to learning of science principles were gradually replaced by "experiments" in laboratories with the expressed purpose of verifying the laws of physics and chemistry. It was believed that students would learn science best by repeating, in an abbreviated fashion, the classical experiments of Newton, Galileo, Hooke, Priestley, Boyle, and many others. Students would see principles of natural science at work and from these observations would come to understand the underlying science concepts.

*Quoted in Ellsworth S. Obourn and John H. Woodburn, *Teaching the Pursuit of Science*, p. 3.

Laboratories and apparatus were designed to duplicate as nearly as possible the materials and equipment used in the original experiments, with "modern" refinements to insure reasonable accuracy in the hands of science students.

As a stimulation to the laboratory approach, Harvard University in 1886 prepared a *Descriptive List* of several score of experiments in physics, emphasizing the verification approach. High school students anticipating entrance at Harvard were required to do these experiments and were subject to examination in the material upon college entrance. A similar list of chemistry experiments set forth in *The Pamphlet* in 1886 was provided for essentially the same purpose.

The effect of these two documents on the direction and scope of subsequent development of high school laboratories and science curriculums was profound. A survey of high school physics and chemistry laboratory workbooks sixty years later revealed that nearly 50 percent of the 1886 Harvard experiments were still retained in the courses of study. As a result of this strong influence, several generations of science students in the first half of the twentieth century were conditioned to the type of laboratory experiments in which the major emphasis was verification and demonstration of known science principles. Little time or guidance was provided for true experimentation upon problems of which the solutions were unknown. The methods of science were taught as procedural formulas to be followed more or less by rote, and with the belief that all problems could be solved in a mechanical, albeit systematic, manner. Students rarely had the opportunity, except on individual projects outside the classroom and laboratory, to experience true scientific endeavors in the solution of "new" problems.

It should be noted that there were some exceptions to this pattern at various times during the period. Occasional conscientious teachers of physics, chemistry, and biology attempted to modify their courses to adopt more of an experimental approach and to give emphasis to inquiry methods. These efforts were sporadic, however, and did not result in general acceptance. The problems of large class size, overworked teachers, shortages of suitable equipment and facilities, and the absence of clear-cut goals for teaching "science and its methods" in place of "teaching about science" prevented the rapid modification of high school science courses.

THE INQUIRY APPROACH

Since the late 1950s we have seen a definite shift in emphasis in high school science. Once again the laboratory has become the center of attention at all levels of secondary science, including the junior high school. The particular goals and methods used in the various new curriculum projects of the Physical Science Study Committee, the Biological Sciences Curriculum Study, the Chemical Education Materials Study, the Chemical Bond Approach Project, the Earth Science Curriculum Project, and others are discussed in detail in Chapter 11. Without exception, these projects emphasize and provide for inquiry methods, in which students themselves are the investigators and opportunities for creativity are abundantly present.

The method of inquiry in the science laboratory can be promoted by a number of fairly simple but important changes. Joseph Schwab, in describing the "inquiring curriculum" has this to say about the methods of inquiry:

> In general, conversion of the laboratory from the dogmatic to the inquiring mode is achieved by making two changes. First, a substantial part of the laboratory work is made to lead rather than lag the classroom phase of science teaching. The reason for this change will be clarified in a moment. Second, the merely demonstrative function of the laboratory (which serves the purpose of the dogmatic curriculum) is subordinated to two other functions.
>
> One of these functions consists in a new service to the classroom phase of instruction. With classroom materials converted from a rhetoric of conclusions to an exhibition of the course of inquiry, conclusions alone will no longer be the major component. Instead we will deal with units which consist of the statement of a scientific problem, a view of the data needed for its solution, an account of the interpretation of these data, and a statement of the conclusions forged by the interpretation. Such units as these will convey the wanted meta-lesson about the nature of inquiry. But they will appear exceedingly easy and simple, conveying little of the real flavor of scientific inquiries, unless the verbal statement of the problem situation and of the difficulties involved in the acquisition of data is given meaning by an exhibition of their real physical referents.
>
> This illustrates the first function of the inquiring laboratory. In brief, it is the replacement of illustrations only of conclusions by illustrations of problem situations.
>
> The second function of the inquiring laboratory is to provide occasions for an invitation to the conduct of miniature but exemplary programs of inquiry. The manual for such a laboratory ceases to be a volume which tells the student what to do and what to expect.
>
> Three different levels of openness and permissiveness are available for such invitations to laboratory inquiry. At the simplest level, the manual can pose problems and describe ways and means by which the student can discover relations he does not already know from his books. At a second level, problems are posed by the manual but methods as

well as answers are left open. At a third level, problem, as well as answer and method, are left open. The student is confronted with the raw phenomenon – let it be even as apparently simple a thing as a pendulum. He pushes and pulls, alters first one and then another of its aspects, begins to discern a problem to be solved, then moves toward its solution.

The inquiring laboratory is characterized by a third general feature: it erases the artificial distinction between classroom and laboratory, between mind and hand. [1]

Richard J. Suchman, in a study with fifth and sixth graders regarding inquiry training, made the following observations:

> The program is designed to train fifth and sixth graders in the skills and methods that are necessary to make systematic studies of the physical world. The pupil learns that when he observes a phenomenon which he does not understand, he need not throw up his hands in despair or ask someone to explain it. He learns to gather data, experiment, formulate and test hypotheses; to break down a confusing tangle of objects and events into variables that can be examined in relation to each other. He learns to study the effects of one variable on another while holding the remaining factors constant. He learns to look beyond the events that are readily observable and to isolate important but elusive conditions. In time he develops a *strategy of inquiry*: a general approach to finding out why a given event takes place. He learns that to predict and control events he must first determine the conditions that are necessary (and sufficient) for the events to occur. By manipulating "cause and effect" in this manner, the inquiring child moves beyond the concrete situation to higher levels of abstraction and generalization, using his own skills and powers of perception.[2]

Alfred Novak reports comments by Dr. Warren Weaver, vice-president of the Sloan Foundation, concerning scientific inquiry in the laboratory at the college-freshman level:

> It seems to me absolutely essential students do something more than listen to lectures, look at demonstration experiments, study a textbook, recite a lesson. The students simply must do something on their own, with their own minds and with their own hands. They must have a scientific experience, even if it is so simple as swinging a bunch of keys hanging on a string and timing this pendulum with their pulse.[3]

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[1]Paul F. Brandwein and Joseph J. Schwab, *The Teaching of Science as Enquiry* (Cambridge, Mass.: Harvard University Press, Copyright 1962, by the President and Fellows of Harvard College), pp. 52-53.

[2]Richard Suchman, "Inquiry Training: An Approach to Problem Solving," *Laboratories in the Classroom* (New York: Science Materials Center, 1960), pp. 73-76.

[3]Alfred Novak, "Scientific Inquiry in the Laboratory," *The American Biology Teacher* 25, No. 5 (May 1963): 342-46.

Novak recommends "laboratories that can run the spectrum from text-centered to the self-energized laboratory which is completely student-centered and student-activated; i.e., completely unstructured by the teacher." He continues:

> In such an array of laboratory experiments, the student emerges from the laboratory with some understanding of the problems and operations of a scientist. He begins to feel his dependence on a conceptual framework that establishes, designs, and directs experimentation. The student learns the limits of both his thinking ability and his perceptual senses. He feels the need for acquiring a certain amount of basic information. He begins to appreciate the "right" tack in the quest for knowledge. He sees the usefulness of various instruments that help him solve the problem. He sees the pyramiding of the problems when his attack on one problem results in four or fourteen more or where two or three minor problems have to be cleared up before the solution to the major problem can begin to shape up. He becomes aware of the amount of routine in the quest for knowledge. He is exposed to failure frequently, but on occasion he feels the excitement of discovery.[4]

The inquiry mode of teaching, in addition to requiring a different philosophical approach by the teacher and students, also demands higher levels of proficiency in the use of the tools of inquiry. These tools consist of the skills needed to inquire into natural events and conditions. For example, one could not learn very much about how forces cause masses to accelerate unless he could make careful measurements of distance, time, force, and mass. To learn the interrelationships between all these factors requires that the skill of measurement be quite highly refined. It would seem necessary to know how to use a meter stick or measuring tape, to read the units correctly, to read a stop watch, to operate a beam balance correctly, and to measure force with a spring scale or some other method. In the classroom, the student needs to have opportunities to practice the skills required for a particular inquiry situation; otherwise, it is likely the experience will be frustrating and the learning minimal.

SKILL DEVELOPMENT IN THE LABORATORY

The complaint has frequently been lodged against science teaching that students and teachers alike have difficulty expressing exactly what the goals of science teaching should be.

In taking up this challenge, an attempt has been made to identify the types of skills which science students ought to "be able to do better"

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[4] *Ibid.*, p. 345.

after having taken the courses in science in the junior high school and senior high school. We have listed five categories of skills: acquisitive, organizational, creative, manipulative, and communicative. No attempt is made to rank these categories in order of importance, or even to imply that any one category may be more important than any other. Within each of the categories, however, an effort has been made to list specific skills in order of increasing difficulty. In general, it was felt that those skills which require only the use of one's own unaided senses are simpler than those which require use of instruments, or higher orders of manual and mental dexterity. The categories and the specific skills within them, with some elaboration, are as follows:

A. Acquisitive Skills

1. Listening—being attentive, alert, questioning
2. Observing—being accurate, alert, systematic
3. Searching—locating sources, using several sources, being self-reliant, acquiring library skills
4. Inquiring—asking, interviewing, corresponding
5. Investigating—reading background information, formulating problems
6. Gathering data—tabulating, organizing, classifying, recording
7. Research—locating a problem, learning background, setting up experiments, analyzing data, drawing conclusions

B. Organizational Skills

1. Recording—tabulating, charting, working systematically, working regularly, recording completely
2. Comparing—noticing how things are alike, looking for similarities, noticing identical features
3. Contrasting—noticing how things differ, looking for dissimilarities, noticing unlike features
4. Classifying—putting things into groups and subgroups, identifying categories, deciding between alternatives
5. Organizing—putting items in order, establishing a system, filing, labeling, arranging
6. Outlining—employing major headings and subheadings, using sequential, logical organization
7. Reviewing—picking out important items, memorizing, associating

8. Evaluating—recognizing good and poor features, knowing how to improve grades
9. Analyzing—seeing implications and relationships, picking out causes and effects, locating new problems

C. Creative Skills

1. Planning ahead—seeing possible results and probable modes of attack, setting up hypotheses
2. Designing a new problem, a new approach, a new device or system
3. Inventing—creating a method, device, or technique
4. Synthesizing—putting familiar things together in a new arrangement, hybridizing, drawing together

D. Manipulative Skills

1. Using an instrument—knowing instrument's parts, how it works, how to adjust it, its proper use for task, its limitations
2. Caring for an instrument—knowing how to store it, using proper settings, keeping it clean, handling it properly, knowing rate capacity, transporting instrument safely
3. Demonstration—setting up apparatus, making it work, describing parts and function, illustrating scientific principles
4. Experimentation—recognizing a problem, planning a procedure, collecting data, recording data, analyzing data, drawing conclusions
5. Repair—repairing and maintaining equipment, instruments, etc.
6. Construction—building needed items of simple equipment for demonstration and experimentation
7. Calibration—learning the basic information about calibration, calibrating a thermometer, balance, timer, or other instrument

E. Communicative Skills

1. Asking questions—learning to formulate good questions, to be selective in asking, to resort to own devices for finding answers whenever possible
2. Discussion—learning to contribute own ideas, listening to ideas of others, keeping on the topic, sharing available time equitably, arriving at conclusions
3. Explanation—describing to someone else clearly, clarifying major points, exhibiting patience, being willing to repeat

4. Reporting—orally reporting to a class or teacher in capsule form the significant material on a science topic
5. Writing—writing a report of an experiment or demonstration, not just filling in a blank but starting with a blank sheet of paper, describing the problem, the method of attack, the data collected, the methods of analysis, the conclusions drawn, and the implications for further work
6. Criticism—constructively criticizing or evaluating a piece of work, a scientific procedure or conclusion
7. Graphing—putting in graphical form the results of a study or experiment, being able to interpret the graph to someone else
8. Teaching—after becoming familiar with a topic or semi-expert in it, teaching the material to one's classmates in such a manner that it will not have to be retaught by the teacher

Some questions might be asked concerning the rationale for emphasis on skill development.

1. *Is there a need for science skill development?* New courses in elementary and secondary schools emphasize the processes of science as much as the concepts and generalizations. Understanding process involves skill competencies. Learning "how to learn" requires adequate learning tools. In addition, students need confidence in their ability to perform the tasks needed in self-learning. Skill competency strengthens self-reliance.

2. *Can skill development be guided through a graded sequence of difficulty — from simple to complex?* This appears possible because of certain characteristics of skills themselves such as level of difficulty and complexity. For example, skills requiring the use of unaided senses are simpler than skills requiring the use of instruments. It is easier for a student to use his unaided eyes to compare the colors of minerals than to operate a petrographic microscope to do the same thing at a higher level of sophistication. Also, groups of simple skills may be included in more difficult complex skills. Graphing, for example, requires competency in the simpler skills of counting, measuring, and using a ruler (instrument). In the same way, higher levels of learning, such as analysis, synthesis, and evaluation, require higher levels of skill proficiency.

3. *Does skill development enhance or preclude concept development?* It seems that growth in conceptual understandings would be enhanced by expertise in skill usage. In teaching skills, concepts form the vehicle by which the skills are learned. One cannot learn a skill in a void — there

must be substantive information on which to operate. The skill of comparing, for example, is useless unless there are things to compare. In the same vein, a hierarchy of skills forms a framework on which concepts can be attached. As one moves toward more and more sophisticated skill learnings, the subject matter (concepts) can be adapted and changed as needs require.

4. *Can achievement of skill competencies be tested?* There is ample evidence that skill achievements can be structured in behavioral terms. Performance can be observed and evaluated. Various performance levels of individual skills can be graded on a continuum from minimum to maximum success. Not only is it possible for teachers to create testing situations using performance objectives, but it is equally possible to provide self-evaluation opportunities for students to gain knowledge of their own progress and levels of performance.

5. *What are the implications of the skill-development approach in the science classroom?* Conditions necessary for success when emphasizing the skill or process goals are as follows:

   a. Time must be provided for practice and experience in the skills being developed. One does not become proficient without practice and drill.

   b. Teachers must have clear understandings of the skill objectives being sought. Planning must revolve around these objectives rather than traditional content goals alone.

   c. Ample materials must be at hand. There must be a "responsive environment" permitting students to operate with the "things of science."

   d. A variety of conceptual materials may be selected to facilitate skill development. Most conceptual themes or topics provide ample opportunities for the teaching of varied skills. In planning for teaching, however, it is important to concentrate on a limited number of skills in any particular lesson.

   e. Evaluation emphasis must be placed on performance or behavioral terms, not mere factual memorization or recitation. The superficial coverage of content must be de-emphasized while performance and depth of understanding must be brought to the foreground.

Mere identification of skills to be taught is, of course, only a first step in the realization of a science objective. In order to bring about skill development and ultimate mastery of the desired skills, the teacher must devise suitable teaching plans and student activities. It goes without saying that, in this type of learning at least, "learning by doing" is an important maxim. Pupils must be given, opportunities to carry out activities which give repeated practice in the skills to be taught. The laboratory becomes an important facility at this point because most of the skills involve procedures which, to a greater or lesser extent, require materials and apparatus.

Two sample lessons oriented toward skill development are given as illustrations:

Lesson I

Grade level: Elementary or junior high

Objectives: To gain practice in the skills of : (a) measurement, (b) record keeping, (c) graphing

Subject: Forces produced by springs

Problem: How does the length of a spring depend on the force exerted on it?

Procedure: Work in pairs, or do as a student demonstration with all students recording the data and drawing the graph.

Set up the spring and weights as shown in Figure 27. Add weights one at a time and check the readings again each time.

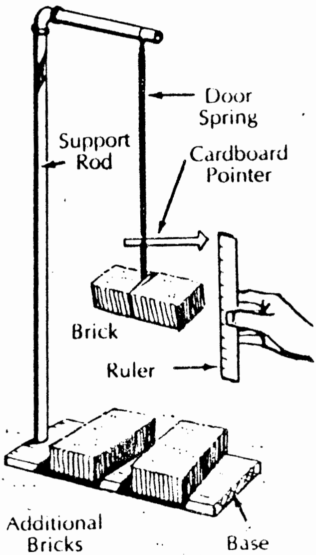


Figure 27

Record the results as shown in Table I.

Graph the results as shown in Graph I.

Graph I

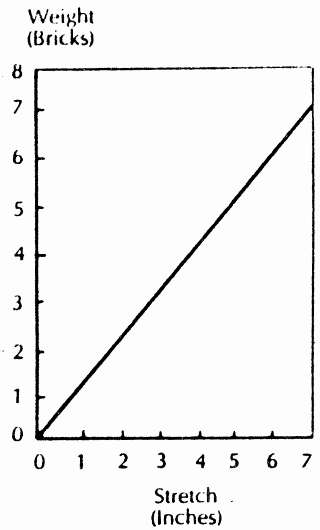


Table I

Weight (Bricks)	Stretch (Inches)
1	1.5
2	3.0
3	4.5
4	6.0

Materials: Door springs, several bricks, ruler, string

Conclusion: The change in length of a spring is directly proportional to the change in the force exerted on it—if the spring is not stretched beyond its elastic limit.

Probable skills developed:

a. Set-up and adjustment of apparatus (manipulative)
b. Observation of initial conditions and changes due to experimental factors (acquisitive)
c. Recording of data (organizational)
d. Graphing and analysis of data (organizational and communicative)
e. Drawing conclusions (organizational)

Evaluation: Can the student—

a. Set up the apparatus for use?
b. Devise a plan of procedure?
c. Read a scale to the limits of its accuracy?
d. Record data in a tabular form?
e. Plot a graph?
f. Interpret a graph?
g. Draw conclusions from the experiment?

h. Recognize sources of error?
i. Report his results in lucid fashion?

Lesson II

Grade level: Senior high

Objective: To gain practice in the skills of: (a) measurement, (b) recording, (c) graphing

Subject: Magnetism

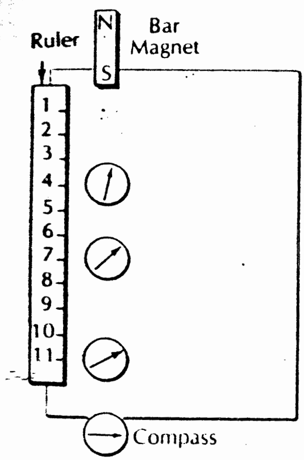
Problem: How does the strength of magnetic force change with distance?

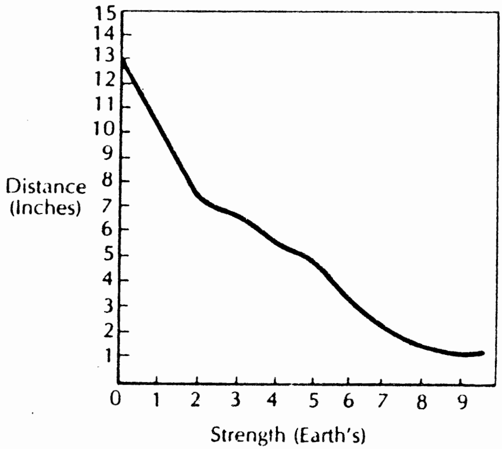
Procedure: Work in pairs. (Also could be done as a student demonstration with all students recording the data and drawing the graph.)

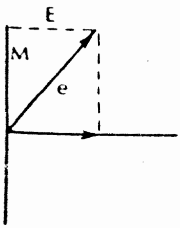
Set up a magnet as shown in Figure 28.

Materials: Compass, bar magnet, ruler, protractor

Conclusion: The strength of a magnetic field decreases inversely with the square of the distance from the magnetic pole.







$$\tan \theta = \frac{E}{M}$$

$$M = \frac{E}{\tan \theta} = \frac{1}{1/\sqrt{3}}$$

Data:

Distance	Angle	Strength (Earths)
13″	90°	0
10″	45°	1
6″	30°	1.732
3″	3°	5

Figure 28

Skills developed:

a. Reading angles from a protractor or circular scale; reading distances on a (1) linear scale (2) logarithmic scale
b. Plotting graphs
c. Analyzing graphs
d. Using trigonometry
e. Writing a report of an experiment

Evaluation: Can the student—

a. Set up the apparatus for use?
b. Gather the necessary materials unaided?
c. Find a N-S direction?
d. Obtain several points of data?
e. Record the data systematically?
f. Calculate the tangent of an angle and compute the strength of magnetic field?
g. Graph the data?
h. Analyze the meaning of the graph?
i. Explain the result to a teacher or other student?
j. Write a suitable report of the experiment?

OPEN-ENDED EXPERIMENTS

The trend toward inquiry and discovery as modes of experimentation in modern secondary school laboratories has been accompanied by replacement and modification of the traditional laboratory workbooks and manuals. Whereas earlier objectives of laboratory work emphasized demonstration, reproduction of classical experiments, and verification of known scientific principles, the modern experiment is more nearly deserving of the label "experimentation." Laboratory guides have been produced in which problems are proposed for study in the laboratory, with a minimum of explicit instructions. Procedures are frequently suggested in general terms, and recommended materials are listed; alternative methods are encouraged. The student is expected to observe his experiment carefully and to report his observations without the restriction of having to arrive at some "correct conclusion" established beforehand. In an elementary sense, the student becomes a true experimenter, employing suitable scientific techniques for the problem at hand. The adjective *open-ended* has been applied to experiments of this type, and this label derives from an effort by the Manufacturing Chemists' Association in 1958 to improve the quality of high school chemistry experiments.[5]

[5] *Ibid.*, chap. 5, p. 20.

The unique characteristics of the open-ended experiments are listed in Chapter 12. Chemistry experiments prepared by the MCA are designed to exploit these characteristics to the fullest extent. New courses in physics, biology, chemistry, earth science, and elementary science in recent years tend to emphasize similar goals in their laboratory work. For example, a typical experiment in the laboratory guide of the Physical Science Study Committee physics course is one dealing with refraction of waves of water in a ripple tank.[6] After carrying out some investigations in answer to guide questions in the experiment, the student is given the following information and questions: "To establish the quantitative relation between the angles of incidence and refraction requires considerable care. Keeping the frequency constant, you can measure the angle of refraction for four or five different angles of incidence. Over what range should you choose the angles of incidence? What do you conclude from your results?" It is apparent here that the student will be required to extend himself beyond the normal laboratory work in order to secure answers to the questions asked of him. Also, he is encouraged to continue study in greater depth in order to refine his results.

Another example of the open-ended experiment—in the laboratory manual of the text, *Investigating the Earth*, by the Earth Sciences Curriculum Project—is an investigation into reflection, absorption, and penetration of radiation that is carried out by a variety of activities. In a section called "Subsequent Activities," the following statements and questions are included:

1. Place flat objects of different materials in the sun. (Include a mirror.) Feel them after a few minutes. Compare their temperatures.
2. Consider that the amount of energy absorbed by a layer of material is proportional to the amount of energy incident on it. Imagine that a medium, say water, is divided into layers. What can you say about the penetration of the incident energy? Will the amount of energy absorbed be the same in each layer?[7]

Here again we see the attempt made to extend the students' investigations in greater depth and perhaps beyond school time in order to secure answers to the questions asked.

A third example of the efforts to make the laboratory an inquiring type of experience and of the open endedness of experiments is an experiment suggestion from the Chemical Bond Approach course. In this experiment, a title, "The Decomposition of Potassium Chlorate (V)" is given. A problem is stated: Devise a series of experimental procedures

[6] *Laboratory Guide for Physics* (Boston: D. C. Heath & Company, 1960).

[7] *Investigating the Earth – Laboratory Manual* (Boulder, Colo.: Johnson Publishing Company, 1964).

to study the decomposition of potassium chlorate (V).[8] This is all the help provided. The student is expected to analyze the problem, design a procedure, prepare apparatus, gather data, analyze the data, draw conclusions, and check the conclusions on his own. Needless to say, a student successful at this type of laboratory procedure will learn much about the ways of a scientist and of the problems of extracting scientific information from nature.

How does the incubator provide several opportunities for open-ended experiments?
Courtesy of the Biology Dept., Oak Park and River Forest High School, Illinois

ORGANIZING LABORATORY WORK

Effectiveness of the laboratory experience is directly related to the amount of individual participation by students. *Individual participation*

[8]Chemical Bond Approach Project, *Investigating Chemical Systems* (New York: Webster Division, McGraw-Hill Book Company, 1963).

here means active involvement in the experiment with definite responsibilities for its progress and success. In theory, the ideal arrangement would be to have each student wholly responsible for carrying out the experiment from start to finish. In this way, the preliminary planning, the gathering of materials, preparation of apparatus, design of the method, collection of data, analysis of results, and drawing of conclusions is unmistakably the work of the individual student, and the accompanying learning is at a maximum.

In reality, the maximum learning may be achieved, for certain students, by working in pairs or very small groups. With good cooperation and sharing of duties, the stimulation of pair or small-group activity may be beneficial. In group work, a shy student may be stimulated into action and thought processes of which he may be entirely incapable by himself. An extroverted student may assume directive and leadership qualities not developed in individual work. The science teacher must be aware of these possibilities and plan the execution of laboratory work accordingly. There ought to be opportunities in the laboratory to provide experiences using both arrangements. Avoidance of stereotyped and inflexible arrangements should be of concern to the teacher of laboratory sciences.

Complexity of experiments will vary greatly. Even in a typical laboratory science, such as chemistry, "experiments" may be no more than carrying out a preplanned exercise of observation and data gathering, or they may be as extensive and demanding as research on a problem whose solution is totally unknown. Arrangements for laboratory work must accommodate these extremes. A student of general science in the junior high school may need more of the "exercise" type of experiment in order to gain the skills needed for complex experiments. On the other hand, he should likewise be afforded opportunities to work on true experiments in order to sense the joy of discovery in the manner of a practicing scientist.

ORIENTING STUDENTS FOR LABORATORY WORK

In general, students of the sciences look forward to a laboratory class with pleasant anticipation. Being pragmatic by nature, they sense that this is "truly science" and that an exciting experience awaits them. This attitude, most prevalent in the junior high school, must be carefully nurtured and guided as the student progresses to more rigorous sciences. If laboratory work becomes a bore because of exc sively rigid formality, unexciting exercises, "cookbook" techniques, or whatever reason, the student effectively will have been lost as a potential science participant. An atmosphere of excitement, curiosity, interest, and enthusiasm for science should be encouraged in the laboratory. This must be tempered by care and restraint in use of apparatus and diligence in the tasks assigned. Obviously a hands-off policy regarding equipment cannot be adopted, nor can a complete laissez-faire attitude be condoned. Respect for the problem, the materials, and the probable results of experimentation must be developed. The laboratory experience is but one vehicle by which the objectives of science teaching are developed. Suitably carried out, it can be one of the most effective methods of teaching and learning.

Orientation for laboratory work may involve creating a suitable frame of mind for the investigation of a problem. The problem must appear real to the student and worthy of study. He must have some knowledge of possible methods of attack. He should know what equipment or apparatus is needed and be familiar with its use. Time for work on the problem must be available to the student. In a given situation, the science teacher may need to give attention to one or more of these factors in order to begin students on their laboratory investigations.

THE PLACE OF DISCUSSION IN LABORATORY WORK

In recent years, there has been a trend toward placement of laboratory work at the very beginning of a new unit of study. The laboratory guide book or manual is designed to identify problems requiring observation and solution. The student performs the assigned tasks or devises procedures of his own to arrive at a solution to the problem. In the course of doing this, he discovers the need for further information in order to explain his observations. He is motivated to read a textbook, search for information in a sourcebook or handbook, read supplementary material, or consult his teacher.

Laboratory work is followed by class discussions, short lectures, or question periods. During these activities, student questions are answered, clarifications of observed phenomena are made, and certain misconceptions may be discussed. Other activities such as problem assignments, projects, extra reading, reports, tests, and demonstrations may follow in their proper context as part of the teaching and learning process.

In this method, it is likely that more than half of the total class time is spent in laboratory activities. The follow-up sessions described above become extremely important. The need for the teacher to ascertain the accuracy of the learned concepts, to correct misconceptions, and to promote maximum learning is usually greater than in a conventional course. At the same time, the student is more directly involved in the task and may be more highly motivated than he would otherwise be.

LABORATORY WORK IN THE JUNIOR HIGH SCHOOL

Extension of laboratory practices to the junior high school is occurring with greater frequency. Facilities for effective laboratory work are being built into modern junior high schools, and youth of this age level are beginning to experience laboratory work on a regular, planned basis. Examples of this trend are the course developed by the Earth Sciences Curriculum Project[9] and the Introductory Physical Science Course of The Education Development Center.[10]

Junior high school students are enthusiastic participants in the laboratory method of teaching. Curiosity and a buoyant approach to learning make this group responsive to the laboratory approach, and proper guidance by the teacher can make this method a fruitful one for junior high school students. Because junior high school science leads to more rigorous and laboratory-oriented sciences in the senior high school, it is worthwhile to consider what its contributions are to more effective learning when the student reaches biology, chemistry, or physics. It is reasonable to assume that certain attitudes, knowledges, and skills learned well in the junior high school can contribute to better and perhaps more rapid learning in the senior high school.

The following is a suggested list of knowledges and skills which might be developed in seventh-, eighth-, and ninth-grade science and which are considered desirable prerequisites for senior high science:

1. To understand the purposes of the laboratory in the study of science
2. To understand and be familiar with the simple tools of the laboratory
3. To understand and use the metric system in simple measurement and computation

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[9] See *Investigating the Earth – Laboratory Manual.*

[10] See *Introductory Physical Science Project*, Education Development Center, 55 Chapel Street, Newton, Mass.

4. To attain the understanding necessary for the proper reporting of observations of an experiment
5. To keep neat and accurate records of laboratory experiments
6. To understand the operation of simple ratios and proportions
7. To be able to understand the construction and reading of simple graphs
8. To understand and use the simpler forms of exponential notation
9. To understand the proper use and operation of the Bunsen burner
10. To use the slide rule for simple operations
11. To be able to understand and demonstrate the use of a trip balance
12. To work with glass tubing in performing laboratory experiments
13. To keep glassware and equipment clean
14. To put together simple equipment in performing laboratory experiments
15. To measure accurately in linear, cubic, and weight units

Laboratory work in the junior high school can be broadened to include such features as out-of-doors observations, excursions, and certain types of project activities, as well as conventional experimentation in laboratory surroundings. Systematic nighttime observations of planets, constellations, meteors, the moon, and other astronomical objects may properly be considered laboratory work. Similarly, meteorological observations and experiments involving record keeping and correlations of data are included under this heading. Excursions for collecting purposes, observations of topographical features, studies of pond life, and ecological investigations are true laboratory work. The narrow connotation of *laboratory work* as something which takes place only in a specially designed room called a laboratory must be avoided in the junior high school sciences.

EVALUATION OF LABORATORY WORK

Broad concepts of evaluation include giving attention to all of the activities which students are engaged in during their secondary school years. With increasing time and emphasis devoted to laboratory work, it becomes necessary to devise suitable methods of evaluating this activity. As with all evaluation, identification of the goals of the activity or teaching method must precede determination of the actual procedures to be used in the evaluations. For laboratory work, a suggested list of goals is as follows:

1. To develop skills in problem solving through identification of problems, collection and interpretation of data, and drawing conclusions
2. To develop skills of manipulation of laboratory apparatus
3. To establish systematic habits of record keeping
4. To develop scientific attitudes
5. To learn scientific methods in the solution of problems
6. To develop self-reliance and dependability
7. To discover unexplored avenues of interest and investigation
8. To promote enthusiasm for the subject of science

Specific activities in which students are usually involved in laboratory work include the following:

1. Planning an experiment and forming hypotheses
2. Planning an excursion for collecting purposes
3. Setting up apparatus
4. Constructing materials and apparatus
5. Observing natural phenomena
6. Observing a process in an indoor laboratory
7. Searching for authoritative documentary information on the topic
8. Gathering data and recording it
9. Collecting specimens
10. Classifying and organizing materials
11. Making modifications of equipment
12. Reading instruments
13. Calibrating apparatus
14. Drawing charts and graphs
15. Analyzing data
16. Drawing conclusions from the data
17. Writing a report of the experiment

18. Describing and explaining an experiment to someone else
19. Identifying further problems for study
20. Dismantling, cleaning, storing, and repairing apparatus

Evaluation of these activities and of the general outcomes of laboratory work may be done in a variety of ways. Among these ways are practical tests, use of unknowns, achievement tests, direct observation of laboratory techniques, written reports, individual conferences, and group conferences.

In a practical test, a student may be directed to perform a certain laboratory task. Direct observation of the techniques used, the correctness of procedures, and the results obtained may be made by the teacher. Procedures such as identification of unknown chemicals, a common practice in qualitative analysis in chemistry, might be extended to earth sciences, biology, and physics. Achievement tests, designed to assess understandings of course content, are an important evaluative technique for laboratory work because of the concern that correct knowledge be obtained through the methods of the laboratory. Pure recognition and recall tests are not usually suitable forms for achievement tests of laboratory experience. Tests which depend upon accurate observation, recognition of pertinent data, and ability to reason logically are more suitable for measuring outcomes of laboratory work.

Writing a Laboratory Report

The written report, a frequently used method of evaluating progress and understandings in the laboratory, needs to be scrutinized. Too often, the written report becomes a stereotyped form which loses its value as an instrument of evaluation. Each student is required to present his information in a standard form that leaves little opportunity for creativity and flexibility.

The following characteristics of a good experiment report point out the essential items required yet leave room for initiative and creativity on the part of the student. In this type of report, the student begins his report with a blank sheet of paper. As he writes, he keeps the following criteria in mind:

1. The reader can tell exactly what the student is trying to find out.
2. The reader can see the procedure the student is using to arrive at an answer to the problem. The description is clear, concise, and complete.
3. The data collected are organized in good form for ease of understanding.

4. All measurements have their proper units attached to them.
5. Diagrams, if used, are sufficiently large for clarity and are carefully labeled. Diagrams are useful only for making more clear to the reader what the experiment is about.
6. Graphs, if used, are titled, labeled, and neatly drawn. The purpose of a graph is to show relationships between data obtained, for the purpose of drawing conclusions about the experiment.
7. Conclusions should give some answer to the problem, based on the data obtained in the experiment.
8. This report should serve the student in the future, as he is reviewing the work of the course, to recall exactly what the experiment was about and what conclusions he reached.
9. The main criterion for evaluation of this experiment report is: Is this report written clearly enough that an uninformed person could read it, know exactly what was being attempted, how it was done, and what conclusions were reached; and, if necessary, could he duplicate the experiment himself, using this report alone as a guide?

What processes of science are involved in this laboratory activity?

Courtesy of Harold Pratt, Science Supervisor, Jefferson County, Colorado

The range and variety of activities performed by students in the laboratory make it necessary to employ a variety of evaluation methods.

A teacher of science must be aware of these and alert to new possibilities as well. Increasing emphasis on laboratory methods is almost certain to broaden, rather than narrow, the range of individual differences among students. Suitable means for evaluating the progress and achievement of these students in their laboratory experiences must be devised.

SAFETY PRECAUTIONS IN THE LABORATORY

An inevitable result of greater student participation in laboratory work is increased exposure to potentially dangerous apparatus and materials. Instead of viewing this fact as a deterrent to the laboratory method of teaching, the alert and dedicated science teacher will approach the problem realistically and will take the proper precautions to avoid accidents among students in the laboratory.

Accidents and injuries in the laboratory frequently occur because of students' lack of knowledge of the proper techniques and procedures. These techniques can be taught in advance if the teacher plans properly. Certain minimum standards of acceptable procedures may be demanded of students before allowing them to work in the laboratory. The motivation to engage in laboratory work is usually strong enough to overcome the student's reluctance to develop the requisite skills, particularly if he is convinced of the inherent dangers and the need for proper safety techniques.

Some general laboratory skills which will prepare the student to work safely are these:

1. Ability to handle glass tubing—cutting, bending, fire-polishing, drawing tubing into capillaries, inserting tubing into rubber stoppers, and removing tubing from rubber stoppers
2. Ability to heat test tubes of chemicals—knowledge of proper rate of heating, direction, use of test tube racks, etc.
3. Ability to handle acids—pouring, proper use of stopper to avoid contamination, dilution in water, return of acid bottles to designated shelves, etc.
4. Ability to test for presence of noxious gases safely
5. Ability to treat acid spillage or burns from caustic solutions
6. Ability to operate fire extinguishers
7. Ability to set up gas generators properly
8. Ability to use standard carpenter tools
9. Ability to use dissecting equipment, scalpels, etc.

In a survey of accidents in high school chemistry laboratories in California, reported by McComber, it was found generally that poor laboratory techniques were responsible for accidents. There were more serious accidents in large classes, and accidents were more frequent when horseplay was involved. Forty percent of the accidents occurred among students who were above average in scientific inquisitiveness. The types of accidents which most frequently had serious results were explosions and burns from phosphorus; the easy availability of dangerous chemicals used occasionally in the normal chemistry course seemed to contribute to accidents as well.[11]

The following safety precautions to be observed in the chemistry laboratory may be put into effect in a school by discussing them with the students, supplying copies for the students' notebooks, and posting them in a prominent place in the laboratory:

A List of Safety Precautions in the Chemistry Laboratory

The work you do in the chemistry laboratory is a very important part of your chemistry course. Here you will learn to make observations of experiments and draw your own conclusions about what you observe. The following is a list of safety rules to follow in making your laboratory work as safe and efficient as possible:

1. Observe all instructions given by the teacher. Ask for help when you need it.
2. In case of an accident, report to your teacher immediately.
3. Be careful in using flames. Keep clothing away from the flame and do not use flames near inflammable liquids.
4. Follow the directions carefully for the handling of all chemicals.
5. If acids or bases are spilled, wash immediately with quantities of water. Be sure you know where the neutralizing solution is located in the laboratory. Ask your teacher how to use it.
6. Read the labels on all reagents very carefully. Make a habit of reading each label twice on any reagent used in an experiment.
7. Dispose of waste materials in the proper receptacles. Solid materials should be placed in special crocks provided for the purpose.
8. Be sure you know the location and proper usage of the fire extinguishers and fire blankets provided in the laboratory.
9. Consider the laboratory a place for serious work. There is no excuse for horseplay or practical jokes in a science laboratory.

[11] Robert McComber, "Chemistry Accidents in High School," *Journal of Chemical Education* (July 1961):367-68.

THE USE OF LABORATORY ASSISTANTS

Preparations for laboratory work require exorbitant amounts of time on the part of the conscientious science teacher. Ordering materials, providing for their storage, inventorying, repairing equipment, and preparing for laboratory experiments daily add up to a tremendous drain on the science teacher's time and energy. Some teachers have developed systems where student laboratory assistants are used to perform many of the tasks needed to carry on successful laboratory programs. One teacher has prepared a handbook for laboratory assistants included here to illustrate the organization of such a program.[12] Students are given credit for participation.

HANDBOOK FOR LABORATORY ASSISTANTS

PHILOSOPHY

Each laboratory assistant should constantly be working to make the Science Department more successful. There are definite responsibilities, duties, and dangers involved in the program for assistants. The department of science depends on you to a great extent. It is expected that each assistant is to be trusted and relied upon to perform his/or her duties properly without the necessity of close supervision.

RESPONSIBILITIES AND DUTIES

It is the purpose of the Laboratory Assistants Program to aid science teachers, help maintain and organize the equipment and supplies of the department, and to improve the science program.

Specifically this includes:

1. The care and organization of the stockroom.
2. The preparation of laboratory exercises and demonstrations for teachers.
3. The preparation of papers, information sheets, class lists and other clerical work for the teachers.
4. The inventorying of supplies.
5. The correction of papers for teachers.
6. The preparation of charts, posters, signs and labeling of shelves, etc.

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[12]Clifford Hofwolt, *Laboratory Science Course Handbook for Laboratory Assistants*. Mimeographed. (University of Northern Colorado, Greeley: Department of Science Education, 1968).

REQUIRED INDIVIDUAL PROJECT

In all classes you will have tests and homework but in the Laboratory Assistants Program an individual project is required instead. One project is required each semester, or a partially completed project will be accepted the first semester if the project is extremely complex and permission has been given in advance.

Project proposal (plan). At the end of the first quarter a proposal should be submitted. If accepted by the science department, the student will then take data in the experiment.

The Project: The project should include a substantial report discussing the project, theories, procedure, data, etc. The report is due the last day of the semester.

SPECIAL SHORT COURSES

Classes on special skills will be conducted at the weekly meetings to improve your abilities.

1. Handling glassware I (cleaning)
2. Handling glassware II (cutting, bending, and assembling)
3. Preparation of solutions (molarity, normality)
4. Safety in the laboratory
5. Analytical weighing
6. Setting up a biology lab
7. Setting up a chemistry lab

GRADING

Grades will be determined and recorded objectively. A conscientious student should receive an A or B in science. However, it is possible to receive a lower grade for unsatisfactory performance. Grades will be based on the following items:

Required Projects: Each laboratory assistant will be required to complete one project each semester. This project may be in any area of science.

Special Projects: Each laboratory assistant should be constantly working to make the Science Department better. Any ideas that you may have for improving the department will be considered a special project when organized and completed by the student. Projects of a student's own initiative must be cleared through a faculty member before starting.

Demonstrations: Teachers will assign demonstrations to the laboratory assistants whose responsibility it will be to find the equipment, set up demonstration and run it at least twice to make certain it works properly.

Laboratory Experiments: Teachers will assign experiments to be set up, and tried by the laboratory assistants. This will include Physics, Biology, Chemistry, Advanced Biology, Biological Science Laboratory Practicals, and Freshman Science. Students are required to clean up the laboratory after the experiments.

Sections: Each laboratory assistant will have an assigned section in the preparation room and will be responsible for organizing it, inventorying, and seeing to the cleanliness of the section. The section assignments will be rotated on a regular basis.

Attendance at Meetings: Failure to come to a meeting may drop your grade.

Daily Grades: Teachers will be evaluating the laboratory assistants at all times for cooperation, fulfillment of responsibilities, and adherence to rules and regulations.

Log Book: Keep a notebook to include daily accomplishments, notes of meetings and special classes, to be turned in at the end of each quarter.

Point System	*Maximum Points*
Section grade =	100 points/week
Preparation of laboratory experiments =	100 points/experiment prepared
Special projects =	200 points/special project
Demonstrations =	100 points/demonstration (if performed for a class)

Semester Grade: Determined from the average of the two quarter grades and the semester special science project.

MEETINGS

All laboratory assistants are required to attend all meetings since this is a credit course.

Meeting Schedule:

Noon meetings every other week on Monday. All students must be present at 12:00 noon. Bring your lunch.

Seventh period meetings on the week when there are no noon meetings (Tuesday, 7th period at 2:10 to 3:05). These meetings are for organizing sections, working on special projects, classes, and individual projects.

PROCEDURE FOR PREPARING A CHEMISTRY EXPERIMENT

I. Obtain experiment number and approximate date it is to be ready.

II. Preparation

- a. Read experiment in laboratory manual.
- b. Read directions in teacher's manual.
  1. Equipment needed
  2. Precautions
  3. Laboratory hints

III. Setup
- a. Check all chemicals, etc.
  (Report anything not available in proper quantities.)
- b. Check to see if solutions are old.
- c. Make all necessary solutions in proper quantities.
- d. Make one set of chemicals per table (8). Label solutions with formula and concentration. Use the correct size bottles.
- 3. If experiment has unknown, prepare a key to unknowns to be turned in.

IV. Perform experiment
- a. Make certain experiment is completely set up.
- b. Check to see if proper results were obtained.
- c. Record data.

V. Experiment report ready

VI. Clean up all glassware and put away all materials after experiment is completed.

PROCEDURE FOR PREPARATION OF DEMONSTRATIONS

I. Find a demonstration to prepare.
- a. Use any source you can find.
- b. Consult with a science teacher.
- c. Use special demonstration books in science department.

II. Read demonstration carefully.

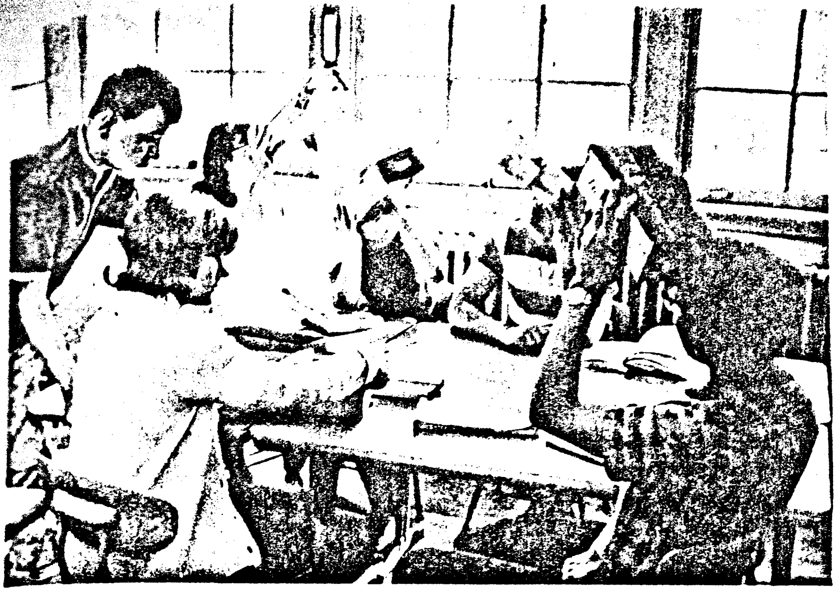
III. Organize, collect all material necessary.

IV. Try demonstration, *perfect it;* be certain that it works.

V. Find out when teachers could utilize demonstration.

VI. Store chemicals in a proper place for safekeeping, and clean up work area.

VII. Perform demonstration.
- a. Give demonstration for proper class, or
- b. Bring in all the material for demonstration (on a cart) for the teacher at the *proper* time.
- c. Don't leave demonstration or experiment lying around if you don't complete it in one period—always put material in proper place even if overnight.



Homemade laboratory equipment serves to motivate and educate.

Courtesy of ESCP, Boulder, Colorado

SUMMARY

Laboratory work in the junior and senior high school is undergoing rapid change. From the emphasis on "verification" experiments in the traditional mode, the student is now invited to "inquire into" or "investigate" a problem. Laboratory experience becomes the initial experience with a new topic of subject matter. This is followed by discussion, reading, and further experimentation. The experiment may lead to new problems which warrant investigation, thus earning the label "open ended." In reporting the results of his experiment, the student concentrates on reporting his observations, his collection of data, his analysis, and conclusions based on the experiment alone. A "right answer" for student *A* may be different from a "right answer" for student *B*. In the new mode of laboratory work, the student learns more accurately what science is. He finds that the process of science may be equal to or more important than the products of science.

The junior high school is becoming increasingly oriented toward a laboratory approach. Not only does this approach give students an early start in learning the methods of science, but certain skills are introduced and practiced which will have value in later sciences taken in the senior high school.

With more of the responsibility for learning in the laboratory being allocated to the student himself, the matter of safety becomes even more important. Care must be taken by the teacher of science to train students adequately in the use of laboratory apparatus and materials. This training may precede actual work in the laboratory or be an intrinsic part of the laboratory work early in the students' experience.

The promise of science for the future has never been greater. A breakthrough has been achieved in which students at last have become participants in the search for knowledge, not mere recipients of facts and generalizations dispensed by authoritative teachers and textbooks. The laboratory is the key instrument in the new mode of science teaching.

Further Investigation and Study

1. Design an experiment which students can do in the classroom or laboratory and which gives practice in the skills of science as discussed on pages 187-90. Choose a particular grade level and select suitable apparatus and materials to achieve the "skill-development" objectives.
2. Suggest a suitable format for a laboratory report in a high school science. Keep in mind that this is not to be a rigorous form but one that is kept flexible and open to student initiative.
3. Study the laboratory guides of several of the following curriculum projects: PSSC, BSCS, CHEM Study, CBAC, ESCP, IPS, and others. What similarities do you find? How do these laboratory guides differ from traditional laboratory manuals? Be prepared to discuss these differences in class.

*I often say that when you can measure what you are speaking about, and express it in numbers, you know something about it; but when you cannot express it in numbers, your knowledge is of a meagre and unsatisfactory kind; it may be the beginning of knowledge, but you scarcely, in your thoughts, have advanced to the stage of "Science," whatever the matter may be.**

Lord Kelvin

10

Methods of Science Teaching: Inquiry through the Use of Mathematics

Mathematics has been an integral part of the advance of science through the years. No scientific discipline has become truly respectable until bolstered by data compiled and analyzed by mathematical methods. The evidence provided by natural phenomena, experimentally tested in the laboratory or in the field and subjected to intensive scrutiny by mathematics, forms the foundation upon which science rests. The data collected by Tycho Brahe did not contribute substantially to the understanding of astronomy until the mathematical genius of Kepler put it into order and formulated certain laws of planetary motion. The hypothesis, developed by Jonas Salk, of polio inoculation by weakened virus did not gain public acceptance until it was tested by statistical methods on a large scale.

*Quoted in Gerald Holton and Duane H. D. Roller, *Foundations of Modern Physical Science* (Reading, Mass.: Addison-Wesley Publishing Co., 1958), p. 229.

The use of mathematics and science in developing attitudes is well expressed in the report of the Cambridge Conference on the Correlation of Science and Mathematics in the Schools.[1]

> Because of the comparative simplicity with which they can go beyond the superficial, science and mathematics lend themselves to the development of attitudes of lifelong and general value. Among these are:
>
> 1. A healthy skepticism regarding accepted knowledge and a willingness to abandon ideas which are demonstrably erroneous.
> 2. The humility inherent in the realization that our understanding can never be complete, coupled with the optimism of conviction that, nevertheless, our understanding can always be increased.
> 3. The realization that understanding, while indeed a means to power, is a joy and an end in itself.
>
> Two hundred years ago a scientist was likely to be conversant with all the fields of science and mathematics. Most scientists worked in only one or two fields, but they managed to keep abreast of important developments in all areas. School work at that time covered the gamut of science and mathematics under the title "natural philosophy." With the exponential growth of knowledge we have long since passed the day when anyone could converse knowledgeably about all fields of science; indeed, there are very few who can keep up with more than a small subarea within a field as broad as biology or mathematics. Because of this, there has been a fragmentation of natural philosophy into different disciplines—mathematics, physics, chemistry, biology, etc. With the recent wave of curricular reform, there has been very little effort to bring these subjects together. Biology is taught with insufficient reference to chemistry; and when chemistry is included, it is not the chemistry of the chemistry curricula. A similar situation exists for chemistry in its reference to physics; and for physics in its reference to mathematics. A course labeled "general science" may nominally touch all areas, but it usually turns out to be a course of relatively thin content designed for the lower-ability students.

The teacher of science in the junior and senior high school has an obligation to convey to his students an understanding of the role of mathematics in science. Every opportunity should be used to show the integral nature of mathematics and science. Because of the usual parallel pattern of science and mathematics courses in grades seven through twelve, little crossover between these disciplines is afforded. The

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[1]*Goals for The Correlation of Elementary Science and Mathematics*. The Report of the Cambridge Conference on the Correlation of Science and Mathematics in the Schools (Boston: Houghton Mifflin Company, 1969).

impression is gained by students that science and mathematics are unrelated entities. This attitude often is perpetuated by the teachers of both subjects, perhaps because of lack of familiarity with possible common objectives and applications.

In practice the difficulty of incorporating mathematics into science classes is compounded by extreme variations in mathematical ability among students. At any grade level, say the seventh grade, students in the science classes have mathematics competencies which range several grade levels above and below the average for the particular grade. Some students may have real difficulties with simple addition and subtraction operations. Others may have good understandings of ratio and proportion, percentage, and use of scientific notation.

It is important for the science teacher to realize this great variation and to plan his science activities accordingly. The mathematical requirements for any given activity or experiment are also extremely varied. By suitably individualizing the instruction, one can challenge students at their level and in the process help them to gain practice in the particular mathematical skill.

Mrs. Phelps planned to have her general science class do a half-life determination using the radioactivity demonstrator. The radioisotope for this experiment was obtained from the Atomic Energy Commission. It was iodine 131 which has a suitably short half-life for classroom purposes.

Certain members of the class whose mathematical abilities were weak were assigned the task of recording the counts per minute registered by the scalar. Simple averaging of three successive readings taken thirty seconds apart was required for each scheduled observation time. Observations were taken every five minutes during each class period for a week. The task was rotated among several students throughout the week.

At the end of a week, the data were plotted on semilog paper. Several of the students needed help on this phase of the experiment. Others were able to handle it with ease.

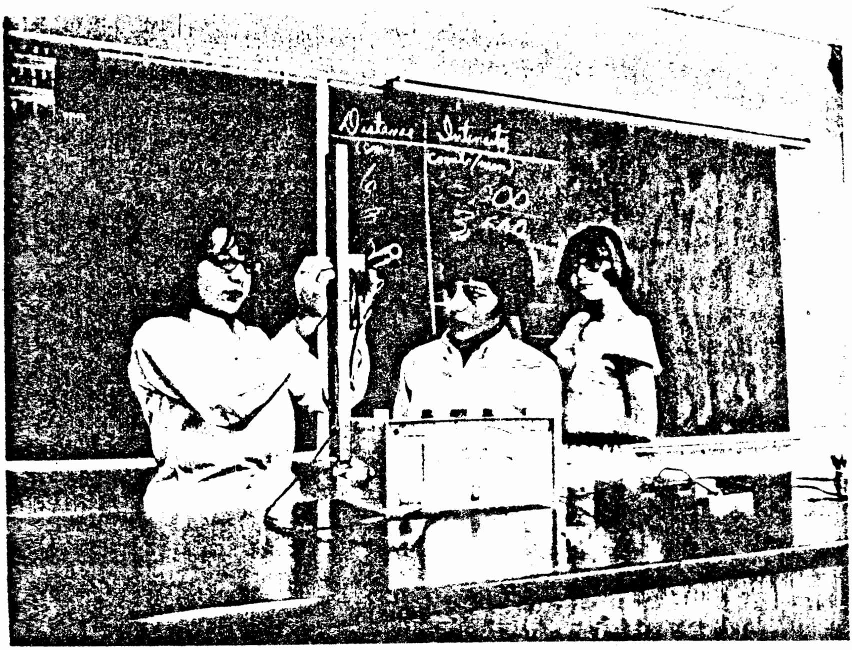
For calculation of the half-life of the sample of iodine 131, a discussion period was scheduled. Questions of the following nature were discussed:

1. What happened to the counts-per-minute rate?
2. What caused this?
3. After what period of time will the count rate be half what the initial rate was?
4. What is the half-life?
5. Why were the data plotted on semilog paper?

6. What would the curve look like if plotted on regular coordinate paper?
7. What will the count rate be at the end of two half-life periods? Three half-lives? Ten?

In this experiment several opportunities were given for development of mathematical skills at varying levels. Counting, recording data, averaging, plotting a graph, analysis of a graph, predicting an outcome, etc., were used at various stages. The range of difficulty of these skills was broad. The teacher could fit the skill difficulties to individual differences within the class and also stimulate growth in previously unlearned skills.

The inquiry approach to science teaching requires increased use of mathematics skills. There are many opportunities for application of these skills in the solution of science problems. These problems are presented or arise normally in the pursuit of laboratory experiments. Junior high school students as well as those at the senior high level have increasing experiences in the laboratory. Solutions of laboratory problems require data. Collection and analysis of data implies mathematical operations.



How will you encourage students to use mathematics in this activity?

Courtesy of Bob Waters, University of Northern Colorado

MATHEMATICS TAUGHT IN THE SECONDARY SCHOOL

Analysis of the mathematics courses in junior high school reveals the following types of skill operations presently being taught, or reviewed:

1. Addition and subtraction
2. Multiplication and division
3. Proper and improper fractions
4. Percentage
5. Ratio and proportion
6. Simple graphing (histograms, line graphs, and bar graphs)
7. Recognition and use of simple geometric figures
8. Area and volume problems
9. Use of units
10. Scientific notation
11. Metric system (mass, length, area, volume)
12. Basic algebra
13. Basic theory of sets
14. Number systems and bases
15. Other introductory topics

At the senior high level, a student is given further experience in all of those operations taught in the junior high school, by way of brief reviews and usage. In addition, the following topics are introduced:

1. Advanced algebra—series and power functions
2. Trigonometric functions
3. Logarithms
4. Coordinate systems in two and three dimensions
5. Use of the slide rule
6. Dimensional analysis
7. Advanced graphing techniques (Log and semilog, reciprocal, reciprocal powers, etc.)
8. Simple statistics (mean, median, standard deviation, quartiles, etc.)
9. Significant figures and standards of accuracy
10. Analysis of errors
11. Elements of basic calculus

For those students in their junior and senior years who are preparing for college, the following competencies are frequently added to the mathematics programs:

1. Solid geometry
2. Analytic geometry

3. Differential and integral calculus
4. Statistical techniques

Development of these skills in mathematics classes should be accompanied by application in science classes. Opportunities for use of these mathematics skills should be provided frequently. Such opportunities should arise in connection with the solution of laboratory problems and exercises, as well as in connection with word problems assigned from the textbooks.

RELATING SCIENCE TO CONCURRENT MATHEMATICS COURSES

Occasional joint planning between the mathematics teacher and the science teacher can bring about improved conditions, in both areas, for relating mathematics and science. If the mathematics teacher is aware of the uses of mathematics in the science classes at particular grade levels, he may point out the possible applications to his students. In assigning homework problems, he may use examples from science which have current significance. Textbooks in mathematics can be improved significantly on this point. The scientist is concerned with proper use of units and measurement. Attachment of appropriate units to the figures given in word problems in mathematics can develop skills of usage, recognition, and manipulation of units by the students. The problems will take on increased meaning and show the applications of mathematics to science.

Team-teaching arrangements between science and mathematics teachers can afford many opportunities for interrelating the two disciplines. Many teachers are trained equally well in both areas and have teaching responsibilities in both. In this case, maximum effectiveness should be achieved.

STIMULATING MATHEMATICS USAGE IN SCIENCE CLASSES

The laboratory provides the opportunity for many data-gathering problems. Practice can be gained in making measurements, keeping records, and graphing.

> For an eighth-grade science project, Edith decided to study the germination of radish seeds under different temperatures.

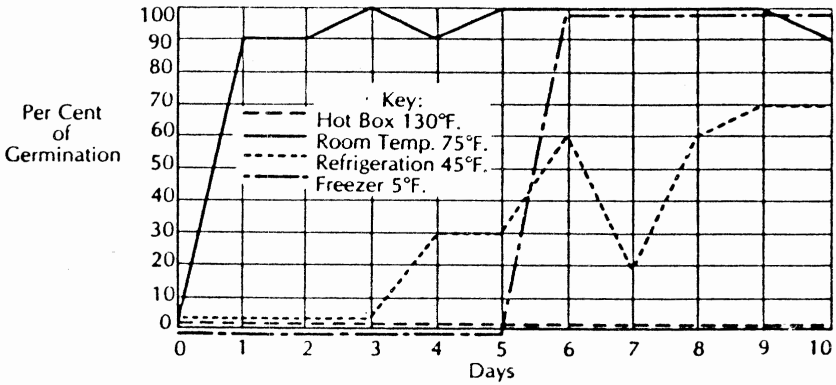
She arranged her radish seeds in rows of ten each on wet cloth, rolled the cloth into a slender cylinder, and placed each in a large-mouth gallon jar with a small thermometer. Ten identical cloths were put in each jar. Four jars were used. Each was placed under a different temperature for the period of the experiment.

Her data sheet looked like this:

PERCENT GERMINATION EACH DAY

	Days									
	1	2	3	4	5	6	7	8	9	10
Room Temp. 75°F (Control)	90	90	100	90	100	100	100	100	100	90
Freezer Temp. 5°F	0	0	0	0	0	100	100	100	100	100
Refrigerator Temp. 45°F	0	0	0	30	30	60	20	60	70	70
Hot Box Temp. 130°F	0	0	0	0	0	0	0	0	0	0

She made a graph of her results as follows:



Analysis of her graph gave an indication of the optimum conditions for germination of radish seeds. It also showed that a colder temperature delays the germination process. The hot-box temperature was evidently too high for germination. Examination of these seeds showed deterioration and decay.

Analysis of experiments gives additional practice in using mathematics. The PSSC exercise entitled "Analysis of an Experiment" is an example of this. The data given in the exercise show a record of the periods of time required to empty a can of water through a hole punched in the bottom.

TIMES TO EMPTY (SEC)

d in cm.	h in cm. 30	10	4	1
1.5	73.0	43.5	26.7	13.5
2	41.2	23.7	15.0	7.2
3	18.4	10.5	6.8	3.7
5	6.8	3.9	2.2	1.5

Students are advised to plot graphs of the data to analyze the relationships between emptying times and two other variables, diameter of hole and height of water in the can. Types of graphs suggested are one showing time versus diameter for a constant height and one showing time versus square of diameter. Graphs for different heights are also suggested. Typical questions asked in this exercise are:

1. From your curve, how accurately can you predict the time it would take to empty the same container if the diameter of the opening was 4 cm.? 8 cm.?
2. Can you write down the algebraic relation between t and d for the particular height of water used?
3. Can you find the general expression for time of flow as a function of both h and d?[2]

The above exercise outline illustrates clearly how use of mathematics gives a student practice in analyzing the results of an experiment. The integral nature of mathematics in science is demonstrated by this example.

Senior high school science students should learn the limitations of measurement, the sources of quantitative errors, and standards of

[2]Physical Science Study Committee, *Laboratory Guide for Physics* (Boston: D. C. Heath & Company, 1960), p. 8.

accuracy. How accurate is a meter stick? To how many significant figures can a measurement be made? Of what value are estimated units? How accurate is a volume computation made from linear measurements which have estimated units? What are possible sources of error in an experiment? To what degree of precision are certain measurements made? How does one express the degree of precision in recording data? The CHEM Study course emphasizes attention to questions like these.[3]

In the *Teacher's Guide*, the following comment is made on "Experiment 5, Heat Effects."

> Post-Lab Discussion. This experiment provides an excellent opportunity to discuss uncertainty both in measurements and in calculated quantities. Begin the discussion by calling for the student values for calculated heat of combustion and heat of solidification. Ask the students about the uncertainty involved in the calculated value. Why is the heat of combustion known only to about ±300 cal/g, and the heat of solidification only to about ±10 cal/g?[4]

Knowledge of significant figures is particularly important in chemistry and physics where physical measurements are made frequently in laboratory experiments. The Appendix contains information on standards of accuracy and significant figures.

Science students can frequently become intrigued by problem situations that require the use of mathematics to solve scientific problems. A few examples of these have been collected by the writers of the Report of the Cambridge Conference on the Correlation of Science and Mathematics in the Schools.[5]

> If cars arrive randomly at an intersection (at a certain rate) and the lights operate regularly, what is the average number of cars waiting for the light to turn green? How does this depend on the timing of the light?
>
> Looking for a needle in a haystack may not be a frequent occurrence; but looking for a ball in a field, a coin in the sand, a hammer in a house, or other lost objects may stimulate thought on the best possible search pattern.
>
> Should one run or walk through a vertically falling rain to keep as dry as possible? If one is served coffee before everything else and wants to keep it as warm as possible, should one put the cream in on arrival or just before drinking the coffee?

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[3] Chemical Education Materials Study, *Teacher's Guide for Chemistry, an Experimental Science* (San Francisco: W. H. Freeman & Co., Publishers, 1963).

[4] *Ibid*, p. 33.

[5] *Ibid.*, p. 95.

How can one get the greatest number of cars into a parking lot, permitting access and egress? If one needs to put in still more cars, how can one do it so as to minimize shuffling?

In what pattern should one mow a lawn to do the least work? How best to rake up leaves is a harder problem.

If you were the manager of a dime store or a supermarket, what principles would guide you in deciding on the number of items of each kind you put on display? Would you display a sample of every kind of item even if it meant crowding together just one of each kind?

Using the Slide Rule

An important adjunct to the development of mathematical competencies is the ability to use a computational device such as the slide rule. Students who develop proficiency in its use will find themselves at a definite advantage when doing problems assigned in science classes and, if permitted, when taking problem-type tests. Most science teachers encourage use of the slide rule in all types of routine calculations when the level of accuracy isn't critical. Since it is the conceptual aspects of the science class that need stressing, anything to minimize the tedious nature of calculations will provide additional time for attention to the principles and concepts under discussion and study.

For most purposes, an inexpensive slide rule will serve adequately. Becoming familiar with its use will allow students who plan on going on in the sciences or engineering to decide on the type of slide rule they wish to purchase later for precise work. Also, the best way to learn how to use a slide rule is to use it repeatedly on problem assignments and calculations. A class period or two devoted to the mechanical features and the skills of manipulation may precede the first assignments. There are on the market certain publications of a programmed nature to assist students in learning about the slide rule and exponential notation, thus strengthening their competencies for classroom work.[6]

Simple Statistics

An aspect of mathematics in science that needs greater attention is the use of simple statistical techniques. Opportunities should be provided for students to assemble data, construct frequency distributions, and calculate certain measures of central tendency such as the mode,

[6]Eugene Roberts, *A Programmed Sequence on the Slide Rule* Chem Study. (San Francisco: W. H. Freeman and Company, 1962); *idem, A Programmed Sequence on Exponential Notation* Chem Study. (San Francisco: W.H. Freeman and Company, 1962).

median, and mean, and certain measures of dispersion such as the range, average deviation, and standard deviation. Exercises requiring these operations will assist students in seeing the intimate relationships between science and mathematics. Certain experiments lend themselves well to statistical computations, particularly those dealing with biological populations or probability problems. Another source of useful data to give practice in statistical methods is the class scores on tests and exercises. Students will profit from the opportunity to work out class averages, range of scores, and standard deviations. If the teacher uses statistical methods in determining grades, this is an opportunity for students to see for themselves the application of statistics to a very real and personal situation. For assistance on elementary statistics, the science teacher might refer to a small reference volume by Douglas[7] or some other more comprehensive statistics textbook.

How is this practice teacher developing rapport with his class?

Courtesy of Ivo Lindauer, University of Northern Colorado

SUMMARY

There is need for greater emphasis on relating mathematics and secondary school sciences. Students of science should see the role of mathematics as a tool of science. Students of mathematics should have opportunities to apply their mathematical skills to the solution of scientific problems; applications should be called to their attention.

[7]Leonard M. Douglas *The Secondary Teacher at Work* (Boston: D. C. Heath Company, 1967).

The development of inquiry methods in science teaching provides numerous opportunities for use of mathematics. In this way, mathematics is seen as a tool of science for quantifying and testing hypotheses. Students receive practice, on a realistic and meaningful level, in the skills learned in their mathematics classes. In addition to practice in the usual skills of addition, subtraction, scientific notation, logarithms, use of the slide rule, etc., students in modern science learn to evaluate measurements, express precision of data and results, work with significant figures, and apply statistical tests to their data. These skills are given practice at all levels of junior and senior high school science. Advanced students use calculus and other higher-level mathematics in some of their science classes.

The advent of new curriculums in science and mathematics is rapidly bringing about a revolution in the traditional patterns of teaching in these subjects. The interrelatedness of the two disciplines is being emphasized with beneficial results to both. Students involved in the modern programs are well-equipped to absorb the skills and concepts required of scientists, engineers, and mathematicians of this technological age.

Further Investigation and Study

1. Plan a laboratory assignment in which students are given maximum opportunity to practice mathematic skills with which they are currently familiar from their mathematics classes.
2. Obtain a mathematics textbook of the type usually used in eighth-grade mathematics. Select an appropriate chapter and rewrite all the problems at the end of a section or chapter in such a manner as to emphasize the interrelatedness of science and mathematics.
3. Interview a teacher of mathematics to discover the types of mathematics skills students are expected to learn by the time they have completed his course.
4. Write a two- or three-paragraph essay on how you would implement the teaching of needed mathematics skills in a science class for which you were the teacher.
5. Discuss the pros and cons of the use of slide rules in science classes at various levels. Give attention to time required to teach rudimentary skill in their use, accuracy, use in tests, etc.

By doubting we are led to inquire, and by inquiry we perceive the truth.
Peter Abelard

11

Secondary Science Curriculums under Change

John Currey, engineer at Rocketdyne Corporation, was invited to speak at Warren High School on Wednesday morning. His topic was "Recent Advances in the Space Sciences." Because it was years since he had visited a high school, Mr. Currey decided to spend the day visiting classes after his talk. A physics class met at 10:00 following the morning assembly. Mr. Currey decided to visit it because the teacher, Mrs. Starks, had mentioned that the class was studying circular motion and centripetal force, topics closely related to Mr. Currey's talk of the morning.

The class assembled quickly and immediately began to work before Mrs. Starks came into the physics laboratory. Materials were ready on the demonstration desk, and students helped themselves to the small kits labeled "Centripetal Force."

Groups of two proceeded to assemble the materials. In a few minutes, trials were being taken and data gathered. A small rubber stopper attached to a string which went through a small glass tube and was fastened to several metal washers was swung in a circle about the head. Revolutions were counted, and several variations of the experiment were tried.

Mr. Currey was impressed. It was obvious the students had prepared before coming to class. They appeared to know how to proceed. Theirs was an interesting way to learn about centripetal force. A simple apparatus was used. Measurements were taken, and data were recorded. The trials were repeated. Several variations were tried; groups were not all using the same procedures. A glance at a laboratory guide revealed only a few guiding questions and hints.

Mr. Currey reflected on how different this laboratory approach was from that of his high school days. There were no blanks to fill in the laboratory manual. The class was not preceded by a discussion of what the students were supposed to find out. There didn't seem to be a rigid procedure. The students seemed honestly interested in finding out the relationships between radius of swing and mass of the washers used in the experiment. There was no evidence of boredom.

A visit to an earth science class for ninth grade brought a few additional surprises. Here a junior high school class was actually experimenting. Its purpose was to measure the diameter of the sun! This was being done by a few measurements of the diameter of a small bright spot on a piece of paper formed by rays of sunlight coming through a pinhole. Solution of a simple proportion gave students the answer. On checking with a few groups, Mr. Currey found that the calculated results varied somewhat, but the students were not especially disturbed. They seemed excited about their accomplishment!

When Mr. Currey left the school at the end of the day he reminisced about his own high school classes. They hadn't seemed nearly this exciting.

What has brought about the change Mr. Currey observed? The date most often referred to as marking the beginning of a serious re-evaluation of our science teaching is October 4, 1957. This was the launching date of the first man-made satellite to orbit the earth. It is interesting to speculate what the reaction would have been if the first satellite had been put aloft by the United States. As it was, the Russian scientists beat our own by a mere four months, and the reverberations set off in education by the rumblings of the first Russian satellite booster are still being felt. Each year brings increasing evidence of the massive reorganization of science curriculums as well as other subjects in our educational system. It is likely that active changes and modernizations will go on for many decades.

It is an exciting time to be entering the science teaching field. Challenging assignments are on every hand; unlimited opportunities for improving existing courses are available in every school system; large-scale curriculum projects are multiplying each year; and innumerable varieties of new teaching techniques and materials are waiting to be tested. There is no limit of valuable work to be done.

THE NEED FOR CHANGE

Science teaching in the secondary school has traditionally been concerned mainly with the products of science. Textbooks in high school physics, chemistry, biology, physical science, and general science have been written predominantly by high school teachers of these subjects. These authors have been concerned with the accurate communication of scientific knowledge to the high school student. In the nature of their positions, they were rarely involved in actual scientific research extracting new knowledge from nature; consequently, the methods of scientific research were given lip service, but students were not given practice in putting these methods to use.

As scientific advances were compounded with increasing rapidity in the first half of the twentieth century, textbooks became larger in order to include the newer advances and applications. The science discipline took on the appearance to the high school student of a compendium of knowledge to be memorized or in some way digested. Little attention was paid to the logic of thought development and to the basic cohesiveness of the discipline.

Recognition of the burgeoning knowledge in each of the sciences led curriculum planners to try new arrangements in sequence. The real problems caused by excessive attention to applications of science knowledge and an encyclopedia approach to the subject were not solved, however.

Forces Which Bring about Change

It has been said that scientific knowledge is increasing at an exponential rate. In the past ten years, it is believed, the total quantity of knowledge in any given science field has more than doubled. The prospects for the future are even more profound. The sheer mass of information accumulated year by year in advancing science fields is a powerful force for change. School curriculum planners are forced to make choices about which information is to be taught and which is not. It is virtually impossible to teach it all.

The advent of Sputnik I was another powerful force. When a rival nation launched a satellite before the U.S. did, it was decided that our educational system needed a severe overhauling, and the secondary science curriculums received the first impact of this view. Results of the revision efforts will be discussed in detail later in this chapter.

A gradual shift in education emphasis from the products to the processes of science is still in progress. The inquiry approach in laboratory work is replacing the verification approach. Less emphasis is being put on memorizing the results of scientific experiments and more upon scientific methods and attitudes of the experimenter.

Recent years have seen numerous innovations in the teaching field, largely spurred by technological advancements. Television teaching, teaching machines, programmed instruction, team teaching, and telelectures have come into use. Problems which were insurmountable a few years ago now are yielding to new audio-visual techniques. Many curriculum changes have come about because of the force of these advancements.

TRADITIONAL SCIENCE COURSES

In order to understand the reasons for the present revitalization of science courses in junior and senior high schools, it is necessary to look briefly at the historical development of the science curriculum.

Secondary science courses have been relatively stable over the years. New courses entered the curriculum from time to time, but only after the character of the school population changed or national emergencies made their existence necessary. Courses which came into being usually found permanent status. Changes were gradual and reflected changing conditions such as industrial advancements, compulsory school laws, or national defense needs.

Each of the traditional courses—physics, chemistry, biology, and general science—will be discussed briefly. The newcomers, physical science and earth science, and the modern versions of all the science courses will then be given consideration.

Physics

Physics first was known as "natural philosophy" and appeared in the academies of the early 1800s. Content was organized into topics similar to those of our traditional courses today. Mechanics, fluids, heat, light, sound, magnetism, and electricity were the topics taught, mainly by recitation. The Civil War and the advent of land-grant colleges in the 1860s placed emphasis on military and vocational aspects of science, and the course became known as physics. Laboratory instruction was emphasized. A list of standard experiments, called *The Descriptive List,* was circulated by Harvard in 1886 for use by the high schools. Candidates for admission to Harvard, who offered physics as a prerequisite, were then tested by use of these experiments.

The content of high school physics remained nearly constant for more than sixty years except for the addition of technological information as new advancements occurred. This information was inserted in or appended to the standard course and the textbooks grew thicker. Little was ever removed, but attempts were made to improve the practical nature of the course.

Laboratory work was guided largely by laboratory workbooks and consisted almost entirely of exercises in verification of physical constants, such as coefficients of expansion, heats of fusion and vaporization, and acceleration of gravity. True experimentation was almost entirely absent from high school physics courses.

In 1956, a group of university physicists at Cambridge, Massachusetts, took a serious look at the secondary school physics curriculum and found it did not represent the content or spirit of modern physics. From this group, the Physical Science Study Committee was formed with the objective of producing a modern course for the high school.

In the four years following, this group developed a textbook, laboratory guide, teacher's guide, set of apparatus, monographs, and films. All of these aids were correlated closely with one another in order to produce an effective teaching package. In addition, there was a large number of summer institutes for upgrading teachers in modern physics and in the philosophy of the new course. The success of this approach to high school physics is still being evaluated.

Some of the important differences between the PSSC course and traditional high school physics are:

1. Fewer topics covered at greater depth
2. Greater emphasis on laboratory work
3. More emphasis on basic physics
4. Less attention to technological applications
5. Developmental approach showing origins of basic ideas of physics
6. Increased difficulty and rigor of the course

Teachers and administrators have conflicting opinions about the merits of the PSSC course. There is general agreement that it is a definite improvement over traditional courses, especially for better-than-average students. For average or below-average physics students, its greater merit is questionable.

In a study by Wasik,[1] PSSC students were found to have significantly higher performance than non-PSSC students in the process skills of application and analysis. On the other hand, non-PSSC students performed at a higher level on the taxonomic process measure of knowledge. It was concluded that the results essentially supported the position of new curriculum writers that the PSSC instructional materials were more effective in developing higher cognitive process skills.

Data from the United States Office of Education in 1967 showed that the PSSC course was taught in approximately 43 percent of the high schools surveyed. However, the total number of students taking physics was only 485,000, about one-fifth of the senior class of that year.

A project has recently been completed in which a course more suitable for the average student was developed. Project Physics, a course produced at Harvard University, attempts to treat physics as a lively and fundamental science, closely related to achievements both in science and outside science itself.[2]

Financial support for the project was provided by the Carnegie Corporation of New York, the Ford Foundation, the National Science Foundation, the Alfred P. Sloan Foundation, the United States Office of Education, and Harvard University. Several hundred participating schools throughout the United States have used and tested the course as it went through several successive annual revisions.

The integral parts of the philosophy of this new course are emphasized in eight points:[3]

1. Physics is for everyone.
2. A coherent selection within physics is possible.
3. Doing physics goes beyond physics.
4. Individual persons need a flexible course.
5. A multimedia system stimulates better learning.
6. The time has come to teach science as one of the humanities.
7. A physics course should be rewarding to take.
8. A physics course should be rewarding to teach.

Materials of the new physics course include a textbook, teacher's guide, student guide, experiments, films, transparencies, tests, film loops, readers, and other items.

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[1]John L. Wasik "A Comparison of Cognitive Performance of PSSC and non-PSSC Physics Students," *Journal of Research in Science Teaching* 8, No. 1 (1971):85-90.

[2]Newsletter No. 1 of the Harvard Project Physics, 8 Prescott Street, Harvard University, Cambridge, Massachusetts, 02138.

[3]Newsletter No. 7 of the Harvard Project Physics, 8 Prescott Street, Harvard University, Cambridge, Massachusetts. 02138.

The chapter headings for the Project Physics course are as follows:

Unit 1 Concepts of Motion
Unit 2 Motion in the Heavens
Unit 3 The Triumph of Mechanics
Unit 4 Light and Electromagnetism
Unit 5 Models of the Atom
Unit 6 The Nucleus

To indicate the rate of growth of enrollments in Project Physics during its development years, the following figures are taken from Newsletter 10:[4]

Year	Number of Teachers	Number of Students
1964-66	16	550
1966-67	55	2,800
1967-68	115	6,509
1968-69	197	8,941
1969-70	432	>20,000
1970-71	(first year of commercial version)	>80,000

Extensive evaluation of the course was carried on during its development. It appears that results are encouraging, both with respect to the performance of Project Physics students on standard tests such as the College Board Examinations and with respect to attracting increasing numbers of high school students to elect physics in their junior or senior years. The percentage of girls taking the course also appears to have increased over PSSC or traditional physics courses.

The school year 1970-71 saw the advent of the final version of the course, published in commercial form, with all the accompanying materials completed. Success of this course now hinges on its adoption by schools throughout the country and the degree to which it attains its objectives.

Other approaches to the teaching of secondary physics have been tried in recent years. A complete physics course on film was produced by a grant from the Fund for Advancement of Education. These were the Harvey White films, each thirty minutes long, which made up a series of 162 films. About 400 educational units involving up to 50,000 students used the films. Several experiments testing the effectiveness of this method of teaching physics were carried out throughout the

[4]Newsletter 10 *The Project Physics Course*, Harvard Project Physics, Longfellow Hall, Appian Way, Cambridge, Mass. 02138.

country. Results indicated that the achievement gains in physics knowledge were about the same as those from conventional instruction; however, definite negative attitudes toward the film course developed among students in the tested schools. Students appear to prefer conventional methods with the major instruction being given by a physics teacher in the classroom.

Several studies have attempted to discern reasons for the dropping enrollments in high school physics. In a questionnaire sent by Thompson to 1,382 high school physics teachers, 79 percent believed students stayed away because the course was too difficult.[5] Of these, 40 percent ascribed their reluctance to fear of jeopardizing their grade average and 16 percent attributed it to fear of mathematics.

In a study of 450 physics students enrolled in Harvard Project Physics in 1966-67, Welch concluded that physics students receive low grades relative to their grades in other courses.[6] In the sample studied, the median I.Q. was at the 82nd percentile but the average grade received by these bright students was in the C+ or B− range. Thus the students were dissatisfied with their experience.

Chemistry

The teaching of high school chemistry began in the early 1800s in girls' academies. The years of the Civil War gave a stimulus to the course because of the military and industrial applications of the science. Laboratory work was increased during those years, and an effort was made to reproduce many of the classical experiments of early chemists such as Priestley and Lavoisier. As with physics, Harvard in 1886 placed chemistry on the optional list for college entrance but controlled the quality of entering students by publishing a *Pamphlet* of sixty experiments, on which the prospective enrollee was tested in the laboratory. The influence of *The Pamphlet* was profound, and the high school chemistry course became highly standardized. Laboratory workbooks were developed, containing "experiments" that were mainly exercises in observation and manipulation of chemical reactions.

With the influx of larger numbers of students in the 1900s, high school chemistry proliferated into a variety of types in an effort to satisfy the needs of students who were not primarily science oriented or who were not planning to enter college. Enrollments in chemistry remained at approximately 35 percent of the eleventh grade, the class in which the course was usually taught.

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[5]Raymond E. Thompson, "A Survey of the Teaching of Physics in Secondary Schools," *School and Society* 98 (1970):243-44.

[6]Wayne W. Welch, "Correlates of Courses Satisfaction in High School Physics," *Journal of Research in Science Teaching* 6 (1969):54-58.

In 1957, a summer conference of chemistry teachers at Reed College in Portland, Oregon, produced a plan for a new type of chemistry course and initiated the Chemical Bond Approach Project. There followed a series of writing conferences, usage by trial schools, and the production of a commercial textbook in 1963. The major theme of this course is the chemical bond, and particular attention is given to *mental models* (conceptual schemes) of structure, kinetic theory, and energy.

The laboratory program and textbook parallel and reinforce each other. No unusual chemicals or equipment are required, and the cost of conducting the CBA chemistry course is not significantly different from that of conducting conventional courses.

A second course-improvement project in chemistry was initiated at Harvey Mudd College in Claremont, California, in 1959. Called the Chemical Education Materials Study, the project developed a course that is strongly based on experiment, with the text and laboratory work thoroughly integrated. In addition to the text and laboratory manual, a teacher's guide, a score of excellent films, and a series of wall charts were prepared.

Both of these chemistry programs received grants from the National Science Foundation, which supported numerous inservice and summer institutes for teachers.

Enrollments in CBA and CHEM chemistry increased initially. In 1968, approximately 40 percent of high school chemistry taught in the United States was the CHEM Study course.[7] Approximately 10 percent of the schools were using CBA chemistry.[8]

At that time, the CHEM project terminated its work and commercial publishers were invited to prepare courses based on the philosophy and materials of the CHEM Study course. Several publishers produced high school chemistry textbooks which appear to be gaining popularity at the present time.

In a survey by Fornoff in 1970, in which 2,395 students were queried, the most widely used high school chemistry textbook was *Modern Chemistry*; *Chemistry—An Experimental Science* was second; and *Chemical Systems* was third.[9] The latter two texts are CHEM Study and CBA chemistry respectively. Some other information obtained in the study showed that the majority of chemistry classes met five times

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[7]*Seventh Report of the International Clearinghouse on Science and Mathematics Curricular Developments, 1970.* Science Teaching Center, University of Maryland, College Park, Maryland, p. 305.

[8]Gordon Cawelti, "Innovative Practices in High Schools: Who Does What—and Why—and How," *Nations Schools* 79: 68.

[9]Frank J. Fornoff "Survey of the Teaching of Chemistry in Secondary Schools" *School and Society* 98 (1970): 242-43.

per week for 40-59 minutes, and 13 percent reported students taking a college level chemistry course in their high school career.

Physical Science

In almost every high school, there is a group of students for whom the traditional science courses of chemistry and physics have seemed unsuitable. For various reasons, such as difficulty with mathematics or abstract reasoning, this group has been somewhat neglected in the typical science sequence. Efforts have been made over the years to serve the needs of this group more adequately through the introduction of physical science, applied science, or "senior science" courses. For some schools, the particular solution has been a satisfactory one depending upon the interest and enthusiasm of the teachers assigned to teach the course. In other schools, the course has been a dismal failure. Phrases like "watered-down physics and chemistry," "bonehead science," or "terminal science" have been sometimes used to characterize the courses tried. No uniformly successful solution has yet been found to accommodate the group of students in question.

The introductory physical science course permits small-group or individual work.

Courtesy of Bob Waters, University of Northern Colorado

In 1965, the Commission of Engineering Education initiated a course for tenth-, eleventh-, and twelfth-grade students in the middle 2/3 of ability in high school. Termed the Engineering Concepts Curriculum Project (ECCP), the course consists of a text, *The Man Made World*, laboratory manual, teachers manual, and discussion games. Approximately 200 teachers have adopted the course for a total of more than 7,000 students.[10] Initial reactions to the course are very satisfactory for the particular group intended.[11]

Biology

This course had its beginnings in botany, physiology, and zoology and was patterned after college courses in these subjects in the nineteenth century. A course of study in biology appeared in New York in 1905, and the College Entrance Examination Board prepared an examination for the course in 1913. Biology was placed in the ninth grade in schools of the six-three-three type of organization and in the tenth grade of eight-four schools.

Of all the high school sciences, biology enjoyed the largest enrollment. A combination of factors operated to bring this about. Placement in the ninth or tenth grade where the effect of school dropout is less pronounced, the effect of compulsory education laws, the nonmathematical nature of the course, and the general requirement of a minimum of one science course for graduation from high school combined to keep enrollments increasing over the years. Approximately 68 percent of tenth-grade students enroll in the biology course.[12]

The biology course changed from one comparable to college courses in botany and zoology and emphasizing systematic study of plant and animal phyla to a descriptive course showing interrelationships between living things and based upon needs and interests of high-school-age young people. Laboratory work was largely based on recognition, identification, and classification of life forms. The absence of plant and animal growing rooms and shortage of equipment resulted in a sterile and textbook-oriented course in many high schools.

To modernize the secondary school biology course, the American Institute of Biological Science in 1958 organized the Biological Sciences

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[10]*Seventh Report of the International Clearinghouse on Science and Mathematics Curricular Developments, 1970* J. David Lockard, Ed., Science Teaching Center, University of Maryland, College Park, Maryland.

[11]E. J. Bongarzone "Citizen's Science: Teaching The Man-Made World," *The Science Teacher* 37, No. 5, (May 1970).

[12]Kenneth Brown and Ellsworth Obourn, *Offerings and Enrollments in Science and Mathematics in Public High Schools 1958* (Washington, D. C.: U. S. Government Printing Office, 1961).

Curriculum Study (BSCS). Arnold B. Grobman of the University of Colorado was appointed director. In discussing the design of the course developed by the BSCS, he said, "A realistic general biology program must take into account a wider range of student ability, interests, and potential than exists in other high school science courses. It must be a course that most tenth-grade students can handle, and at the same time prove challenging to the above-average student. For these reasons the committee thought it undesirable to limit the course to a single design."[13]

Three separate courses were developed, based upon a molecular approach, a cellular approach, and an ecological approach, respectively. Although the courses are different in emphasis, several common themes run through them:

1. Change of living things through time-evolution
2. Diversity of type and unity of pattern of living things
3. Genetic continuity of life
4. Biological roots of behavior
5. Complementarity of organisms and environment
6. Complementarity of structure and function
7. Regulation and homeostasis: the maintenance of life in the face of change
8. Science as inquiry
9. Intellectual history of biological concepts[14]

A complete set of materials is provided for the course. Textbooks, laboratory guides, teacher's guides, supplementary readings, and tests are but a few of these materials. Innovations include the Laboratory Blocks, consisting of a series of interlocking and correlated experiments on a special topic of biology. Eleven different "blocks" have been developed, including, for example, "Plant Growth and Development," "Microbes: Their Growth and Interaction," and "Interdependence of Structure and Function."

A second-level course has been prepared for advanced biology, and a simpler course called *Biological Science: Patterns and Processes* has been designed for slower learners.

Other supplementary materials are excerpts from historical papers, BSCS Invitations to Inquiry, discussion outlines for the laboratory,

[13]Quoted in American Association for the Advancement of Science, *The New School Science: A Report to School Administrators on Regional Orientation Conferences in Science*, Publication No. 63-6 (Washington, D.C., 1963), p. 27.

[14]*Ibid.*, p. 29.

films on laboratory techniques, the *BSCS Teacher's Handbook*, the BSCS Pamphlet Series, and many other materials.

The BSCS biology courses are receiving generally favorable response throughout the country. Several versions of the course are available, and it has been found that different versions are chosen in different regions. Several foreign countries also are experimenting with the course.

Considerable research has been done on the effects of BSCS biology in the schools. In one study, George found that students taking the Blue Version of the course scored significantly higher on critical thinking, as measured by the Watson Glaser Critical Thinking Appraisal Form ZM, than did students taking conventional biology.[15] Adams found that there was no difference in the retention of biological information between BSCS students and those taking traditional biology.[16] However, there were significant relationships between retention and intelligence, reading scores and teacher grades with the BSCS students scoring generally higher. Granger and Yager found no significant difference between students experiencing BSCS and non-BSCS backgrounds with respect to achievement in either high school or college level biology.[17] However, a significantly larger percentage of BSCS students felt their background was better in meeting individual needs, as well as preparing them for college level biology. Carter and Nakosteen, in a study with 8,500 college freshmen, found that BSCS students scored at a superior level on inquiry and recall items on the BSCS Comprehensive Biology Test than did students who had a non-BSCS course in high school.[18]

Junior High School Science

Science in the junior high school has been faced with perplexing problems since its inception. General science was the course offered in the ninth grade of eight-four schools at the time the first junior high schools came into existence. Begun in the decade 1910-20, the course was designed to satisfy the needs and interests of students in early adolescence. The first course was established through research and was designed to fill a current need.

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[15]Kenneth D. George, "The Effect of BSCS and Conventional Biology in Critical Thinking," *Journal of Research in Science Teaching* 3 (1965): 293-299.

[16]B. J. Adams, "A Study of the Retention of Biological Information by BSCS Students and Traditional Biology Students," Ph. D. dissertation, Colorado State College, 1968.

[17]Charles R. Granger and Robert E. Yager, "Type of High School Biology Program and Its Effect on Student Attitude and Achievement in College Life Science," *Journal of Research in Science Teaching* 7 (1970): 383-389.

[18]Jack L. Carter and Alan R. Nakosteen "Summer: A BSCS Evaluation Study," Newsletter 42, *The Biological Science Curriculum Study*, Feb. 1971.

With the rapid development of junior high schools in the 1920s and 1930s, general science was adopted as a suitable course for the seventh and eighth grades as well as the ninth. Some of the factors operating at that time which encouraged the development of the general science course were:

1. Influx of larger numbers of students into the schools at grades seven, eight, and nine because of compulsory-education laws which kept children in school to age sixteen
2. Increasing concern for a type of education which was needs-centered and designed for life itself
3. Recognition of the importance of a continuous sequence of science offerings from grades one to twelve, with planned long-range goals

The difficulties encountered in junior high school science were of the following nature:

1. A shortage of well-trained general science teachers. Many teachers at this level were physics, chemistry, and biology teachers whose primary interest was not with the problems of junior high school science. Also, teachers in other disciplines such as English, mathematics, and physical education were recruited to teach science. For these reasons the general science texts for these grades were written in an effort to relieve this problem, but the variations in school organization such as six-three-three, eight-two-two and eight-four necessitated a considerable degree of repetition of science topics in order to produce universally salable textbooks.
2. Deficiencies in equipment and facilities for teaching science. Many science classes were taught in ordinary classrooms without water or gas outlets and without adequate facilities for demonstrations and experiments.
3. Lack of clear knowledge of what junior high school science should actually accomplish. Objectives ranged from "preparation for the rigorous science courses in the senior high school" to "general education for good citizenship." Much thought was given to development of attitudes and interests. Some felt general science should be exploratory in nature. Courses designed around this premise became rapid surveys of chemistry, physics, astronomy, meteorology, biology and geology. Others believed students should study the applications of science in

the world around them. Courses of this kind dwelt on home appliances, transportation, communication, health problems, and natural resources.

Enrollments in general science grew to about 65 percent of the ninth-grade classes by 1956, then declined as substitute courses began to permeate the ninth grade and as the seventh and eighth grades took over more of the general science offerings.[19]

NEW SCIENCE COURSES IN THE JUNIOR HIGH SCHOOL

Revision of junior high school science courses through national curriculum studies was delayed while attention centered on the senior high school courses.

Early in 1963, a grant was made to the American Geological Institute to support a curriculum development, called the Earth Science Curriculum Project, for the ninth grade. This is an inter-disciplinary course in the areas of geology, meteorology, astronomy, and oceanography. Its emphasis is on laboratory and field study in which students actively participate in the genuine process of scientific inquiry.

Materials of the ESCP include a textbook-laboratory guide combination, teacher's guide, films, laboratory equipment and maps, and a pamphlet series. After three years of testing and preparation of materials, the course was published commercially. The project continued its programs until 1969, when two offshoots, Environmental Studies (ES) and Earth Science Teacher Preparation Project (ESTPP), were initiated to deal specifically with the problems of teacher preparation in the earth sciences.[20]

Enrollments in earth science continue to grow. In 1969, an estimate of the total public school ninth-grade enrollment, made by the U.S. Office of Education, was 3,218,000, with earth science enrollment at 841,422.[21] Earth science represents 26.2 percent of the total enrollment, an increase over 1967 figures.

A serious problem faced by the ESCP was the preparation of teachers qualified to teach the course, because of the increasing demand for

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[19] Brown and Obourn, *Offerings and Enrollments.*

[20] Newsletter No. 1 of the Environmental Study and Earth Science Teacher Preparation Project, Box 1559, Boulder, Colorado, November 1970.

[21] Newsletter No. 20 of the Earth Science Curriculum Project, Box 1559, Boulder, Colorado, October 1969.

earth science teachers over the past decade.[22] While recent efforts in teacher preparation have narrowed the gap between supply and demand, there is still a shortage.

Moreover, a large number of present earth science teachers are inadequately trained. In many cases they have been "recruited" from other subjects and must be retrained in the use of ESCP materials if the course is to succeed.

Certification requirements vary widely from state to state.[23] Twenty states have no requirements for teaching earth science. New York, on the other hand, requires a minimum of fifty-seven semester hours in science and mathematics and the equivalent of three full-year courses in earth science.

Students learn about the environment through involvement.

Courtesy of ESCP, Boulder, Colorado

A second junior high curriculum development is the Secondary School Science Project of Princeton University.[24] This project, also

[22]Newsletter No. 2 of the Earth Science Curriculum Project, Box 1559, Boulder, Colorado, January 1964.

[23]Newsletter No. 3 of the Earth Science Curriculum Project, April 1964.

[24]Secondary School Science Project, *Progress Report III* (Princeton, N. J.: Princeton University, Winter 1965).

supported by the National Science Foundation, concentrates on the earth sciences, mainly geology. A unit, "Time, Space, and Matter," was developed in preliminary textbook form and was accompanied by kits of equipment and materials. The aims of this course are expressed in the *Progress Report*, which states:

> Over the past twenty years, the changes that have occurred in the world—particularly the phenomenal growth of science and technology—have created an urgent need for a more dynamic approach to science instruction. Our knowledge of the physical world has become so vast and is changing so rapidly that it is no longer feasible, even if it were desirable, to present science to students as a compendium of all that has been learned through the ages. The study of science today must offer the student not merely an account of what has been discovered, but a systematic and logical method of thinking for himself.[25]

Eight regional centers with fifty-six participating schools throughout the nation tried out the materials of the Secondary School Science Project in 1965. The course was published commercially in 1968 and included items such as student equipment packages, class equipment, teacher equipment packages, student investigation books, science reading series, and teacher folios.[26] The course "consists of nine interrelated investigations which enable the student to learn something about the nature and history of the physical world through direct observation and inference."[27]

A third program developed for the junior high school is that of the Introductory Physical Science Program of Educational Services, Incorporated.[28] This project was supported by the National Science Foundation. Its purpose was to develop a one-year course in physical science for use in junior high schools. Laboratory work is emphasized, and equipment has been designed in such a way that students can perform the experiments in ordinary classrooms. The Table of Contents of the IPS course includes the following topics:

Chapter I	Introduction
Chapter II	Quantity of Matter: Mass
Chapter III	Characteristic Properties
Chapter IV	Solubility and Solvents

[25] *Ibid.*, p. 9.

[26] *Time Space, and Matter—Conspectus* (Princeton, N. J.: Princeton University, 1968).

[27] *Ibid.*, p. 13.

[28] *Preliminary Edition: Introductory Physical Science Program* (Watertown, Mass.: Educational Services, Incorporated, 164 Main Street, 1964).

Chapter V	The Separation of Substances
Chapter VI	Compounds and Elements
Chapter VII	Radioactivity
Chapter VIII	The Atomic Model of Matter
Chapter IX	Sizes and Masses of Atoms and Molecules
Chapter X	Molecular Motion
Chapter XI	Heat

This pupil is using IPS equipment. What is he learning by his involvement?

Courtesy of Harold Pratt, Science Supervisor, Jefferson County, Colorado

The Introductory Physical Science course was tested in a number of centers throughout the United States and the materials, which included textbooks, teachers' guides, laboratory notebooks, and extensive apparatus kits were made available through commercial sources in 1967.

The attractiveness of the IPS course to better-than-average junior high school students was made clear in the results of a test survey of representative IPS students in the 1965-66 school year. "In that year 1,005 ninth-grade IPS students and 400 eighth-grade IPS students took the School and College Abilities Test (SCAT) Survey Form, a test of verbal and mathematical ability. The results made it clear that the IPS students were more scholastically able on the average than typical junior high school students in the nation."[29]

As the success of a new course is dependent on well-qualified teachers, the National Science Foundation supported a program to locate qualified science teachers and to prepare them to instruct other teachers in the use of IPS. The program was quite successful and made use of IPS workshops at which teachers were trained by their peers in the local environment.[30]

Several other junior high school courses have appeared on the scene in recent years. Among these are the Intermediate Science Curriculum Study (ISCS) financed by the U. S. Office of Education and National Science Foundation and developed at Florida State University. "The fundamental assumption underlying the ISCS plan is that science at the junior high school level serves essentially a general education function."[31] Three levels corresponding to the junior high school grades seventh, eighth, and ninth were prepared. Level I for seventh grade was tightly structured. Its title, *Energy, Its Forms and Characteristics* permitted students to delve into physical science principles dealing with things of science in their environment. Level II puts the student more and more on his own in designing experiments and recording and interpreting his data. This level deals with *Matter and its Composition and Model Building.* Level III for the ninth grade deals with biological concepts and is designed to use laboratory blocks of six to eight weeks in length as its basic plan of operation. The student is expected to use the concepts and investigative skills acquired in the seventh and eighth grades. All of the class activity in the ISCS course is planned for individualized work. The teacher's main duty is assisting students to work on their own. No formal lectures or information-dispensing sessions are planned for the course, unless needed on a short-term basis by a small group of students.

An innovative feature of the ISCS course is the production of a complete course on Computer Assisted Instruction (CAI). Using behavioral objectives and a system of computer feedback, it was possible to obtain detailed information on the progress and problems encountered by each student working in the system. This information was used to modify and revise the trial versions of the course.

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[29] *Introductory Physical Science—Physical Science II: A Progress Report* IPS Group, Educational Development Center, 55 Chapel Street, Newton, Massachusetts, 02160, 1968, p. 16.

[30] *Ibid.*, p. 10.

[31] David D. Redfield and Stewart P. Darrow, *The Physics Teacher* 8 (April 1970): 170-180.

Other smaller scale projects for revision of junior high school science have appeared on the scene. Among these are the Interaction Science Curriculum Project (ISCP), Ideas and Investigations in Science (IIS), and Patterns and Processes in Science. Each of these has been developed by a commercial publisher, has taken a particular point of view with respect to inquiry-oriented science teaching, and has developed suitable materials to accomplish the task. Each has been extensively field tested and certain elements of success have been claimed. It is safe to say that the field of science teaching in the junior high school has received an impetus in recent years fully equivalent to that enjoyed by senior high school teaching a few years earlier. Since the basic philosophy in the two areas appears to be the same, it is likely that pupils fortunate enough to participate in new courses at both the junior and senior high school levels will be prepared in science more effectively than heretofore.

A complete listing of the current and recently completed science-course-improvement projects is given at the end of this chapter.

Measurements of natural phenomena produce interest and motivation in new science curriculum courses.

Courtesy of ESCP, Boulder, Colorado

COMMON ELEMENTS OF THE NEW COURSES

Surveying the materials of the several new courses which have been developed in secondary school science, one is impressed by their close similarity in types of materials offered and in general objectives. The following common elements are discernible:

1. Their respective brochures and descriptive literature proclaim them to be designed not especially for an elite group but for the students customarily enrolled in secondary science courses.
2. There is less emphasis on applications and technology than in the traditional courses.
3. There is more emphasis on abstractions, theory, and basic science.
4. There is increased emphasis on discovery-type laboratory. Students are given practice in extracting information from nature.
5. There is more rigorous treatment of subject matter.
6. Quantitative techniques are used frequently. Practice is given in data gathering, recording, graphing, and analysis.
7. They present newer concepts in their subject matter.
8. They involve upgrading of teacher competency for successful teaching of the courses. An extensive program of summer institutes and inservice institutes, financed by the federal agencies, is an intrinsic part of most of the new curriculum programs.
9. They are accompanied by a large variety of teaching aids, well integrated and designed to supplement the courses.
10. Their construction has embodied good teaching and learning practices. Students are active participants in the learning process and carry more responsibility for their own learning than in traditional courses.
11. They include many clever innovations, many of which are adaptable to traditional courses.
12. They give opportunities for the good student to extend his exploration of the subject.
13. They are flexible enough that average and below-average students can make acceptable progress within the framework of the course.
14. They present science in a favorable light and provide an understanding of what a scientist is and does in our society.

The common elements indicate certain aspects of curriculum development in science which have become more prominent the past few years.

While the secondary science teacher is concerned mainly with new materials at his teaching level, it is important to note that pupils entering his classes may have been involved in elementary science programs which were innovative and forward looking. It is important to be aware of the new thrusts in science teaching at the elementary level which contribute markedly to the attitudes, knowledge, and competencies of students entering the secondary school.

Some of the elementary science curriculum projects currently in existence are the following:

a. Elementary Science Study (ESS), a project developed by Educational Development Corporation of Newton, Massachusetts. This project developed approximately 75 units in physical and biological science for grades K-6. Its philosophy promotes essentially child-centered investigations of nature with teacher guidance and direction.
b. Science, A Process Approach (SAPA), developed by the American Association for the Advancement of Science, Washington, D. C. This project emphasizes development of process skills such as observing, inferring, predicting, hypothesizing, manipulating variables, developing space/time relationships, etc. The program has been widely adopted in grades K-6 in several states.
c. Science Curriculum Improvement Study (SCIS) developed at the University of California at Berkeley. Several topics in the physical and biological sciences such as material objects, interactions, relativity, organisms, and populations have been prepared for several grade levels. The major emphasis is placed on becoming familiar with some important topics in science and using investigative techniques to study them.
d. Conceptually Oriented Program in Elementary Science (COPES) presently under development at New York University. In this program, five large themes have been chosen as bases upon which to build a coherent view of science. The themes are The Structural Units of the Universe, Interaction and Change, Conservation of Energy, Degradation of Energy, and The Statistical View of Nature.

All of the above programs except COPES have undergone extensive trial testing and revision in elementary classrooms. At this time, all but

COPES are commercially available in complete form. Some school systems have adopted a particular program totally for their elementary science curriculum. Other schools have tried several and developed their own programs using the materials of the new projects. Unquestionably, the ferment in elementary science because of the proliferation of the federally funded projects will have a tremendous impact on the science education of elementary children and will affect the junior high and senior high science programs markedly.

IMPLICATIONS FOR THE SCIENCE TEACHER

The science teacher today is faced with enormous responsibilities. In addition to keeping up with his day-to-day teaching, he must remain alert to current changes and improvements. The swing toward "discovery" and "inquiry" methods demands the best possible knowledge of his subject. He must become well informed about new teaching materials and audio-visual devices. He is faced with certain decisions concerning the adoption of new courses. Having decided to try one or the other in his classroom, he must become thoroughly familiar with its content and philosophy.

In return for this excessive load and responsibility, the science teacher today works in a generally favorable climate of cooperation. Parents and school administrators recognize the need for modern and effective science courses in the schools. Support for better classrooms and laboratories is generally forthcoming.

In addition, the dedicated science teacher is challenged by new teaching methods and stimulated by new courses. The excitement of participation in a testing program for a new curriculum project or the thrill of creative opportunities provided by teaching a new course is ample payment for the extra responsibilities. A science teacher today works in a lively, growing era of change with unlimited horizons.

SUMMARY

The need for changes in secondary school science became increasingly evident midway through the twentieth century. A number of forces at work brought about conditions which affected the curriculum. The rapid increase in scientific knowledge, the competitive nature of the race for space, technological advancements in teaching tools, and a gradual dissatisfaction with the encyclopedic approach to the teaching of science combined to bring about changes.

The first secondary science course to react to these pressures was physics, followed by chemistry, biology, and junior high science, in that order. New courses for all these subjects appeared, stimulated by massive financial support from the National Science Foundation and a few other agencies. The final effects of these large-scale curriculum revisions are not yet known. Teachers of these subjects have taken up the challenge for the better teaching of science by attending summer institutes and inservice institutes for upgrading their own competencies.

Students of the secondary school sciences are being given opportunities for increased laboratory work and application of inquiry methods for learning. They are directed to better understandings of how scientists work and how knowledge is obtained. More attention is given to the processes of science. New apparatus and facilities promote investigations of natural phenomena, while the teacher becomes more of a director of research than a dispenser of knowledge.

At the same time, numerous new curriculums in science for the elementary school are being developed. The philosophy of inquiry and investigation pervades these new efforts and, in all likelihood, will have an effect on the preparation of pupils entering the secondary schools.

The impact of modern curriculum changes will be felt for many years. It is doubtful whether as stable a pattern of science offerings as that characteristic of the first half of the twentieth century will again be achieved. Science of the future will need to be dynamic and changeable in order to meet the demands of a rapidly accelerating scientific age. As the new modes set by the current curriculum revisions become more widely established, students of science will gain the skills and knowledge needed to handle the problems of this age successfully.

Further Investigation and Study

1. Write to each of the curriculum projects listed on page 254 and request their latest reports. Prepare a brief summary of their aims, materials available, and current status.[32]
2. Obtain from your state department of education information on the numbers of schools using the new courses in your state. Prepare a graph showing the trends over the past five years. What are the prospects for the next five years?
3. After studying the materials of one of the new courses in your field of teaching interest, make a list of the demonstrations or experiments which could be adapted satisfactorily to a traditional science course. Illustrate the modifications that would be necessary.
4. How do the new courses handle problems of individual differences? Cite examples of how this is done. Are these materials suitable for individual instruction?
5. What advantages can you see in the new courses? What disadvantages are there? How might the disadvantages be overcome?
6. Write a prediction of what science teaching will be like ten years from now. What new courses, probable technological improvements for the classroom, trends in teacher needs, revisions in objectives, etc., can you foresee?

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[32]Excellent summaries of the activities of all the elementary, junior high, and senior high science curriculum projects can be found in the International Clearinghouse Reports, J. David Lockard, Ed., University of Maryland, College Park, Maryland.

A List of Science Curriculum Projects for the Secondary School (Projects and Original Directors)

Biological Sciences Curriculum Study, University of Colorado, Boulder, Colorado. Dr. Arnold B. Grobman, director.

Chemical Bond Approach Project, Earlham College, Richmond, Indiana. Dr. Laurence E. Strong, director.

Chemical Education Materials Study, University of California, Berkeley, California. Dr. George C. Pimental, director.

Earth Science Curriculum Project, P. O. Box 1559, Boulder, Colorado. Dr. Robert L. Heller, director.

Engineering Concepts Curriculum Project, The Polytechnic Institute of Brooklyn, 333 Jay Street, Brooklyn, New York 11201. Dr. E. J. Piel, executive director.

Harvard Project Physics, Pierce Hall, 29 Oxford Street, Harvard University, Cambridge, Massachusetts. Dr. Gerald Holton and Dr. Fletcher Watson, codirectors.

Ideas and Investigations in Science, Prentice-Hall, Educational Book Division, Box 900, Englewood Cliffs, New Jersey 07632.

Intermediate Science Curriculum Project, Rand McNally and Company. Chicago, Illinois.

Intermediate Science Curriculum Study, The Florida State University, Tallahassee, Florida. Dr. Ernest Burkman, director.

Introductory Physical Science Program, Educational Services, Incorporated, 164 Main Street, Watertown, Massachusetts. Dr. Uri Haber-Schaim, director.

Physical Science Study Committee, Educational Services, Incorporated, 164 Main Street, Watertown, Massachusetts. Dr. Jerrold R. Zacharias, director.

Patterns and Processes of Science, D. C. Heath and Company, Boston, Massachusetts.

Secondary School Science Project, Princeton University, Princeton, New Jersey, Frederick L. Ferris, director.

The Secondary School Curriculum Projects[33]

In December 1962, the American Association for the Advancement of Science established an Information Clearinghouse on New Science and Mathematics Curricula at the University of Maryland Science Teaching Center in College Park. Activities of the Clearinghouse include the collection of data on new and continuing projects, the deposition of such curriculum materials for study and perusal by others, and the dissemination of pertinent information to interested individuals and groups. Material has been furnished to the Clearinghouse from local, state, and national programs in the United States and from several projects in foreign countries. Over 350 individuals, including the directors of the college commissions, have been contacted for K-16 information for the annual reports.

The following chart summarizes information about the activities of major ongoing projects in science curriculum for secondary schools. The excerpts here are from the Seventh Report of the International Clearinghouse on Science and Mathematics Curricular Developments March 1970. That publication consists mainly of information on the most recent project activities as reported by the project directors themselves.

[33]Text and summaries by J. David Lockard (Director, AAAS Information Clearinghouse, University of Maryland, College Park).

BRIEF SUMMARIES OF SCIENCE CURRICULUM PROJECTS OF PARTICULAR INTEREST TO SECONDARY SCHOOL SCIENCE TEACHERS

PROJECT NAME	ORIGINAL DIRECTOR'S NAME/ PROJECT ADDRESS	SUPPORT: ORGANIZATIONAL/ FINANCIAL	GENERAL PURPOSE	SCIENCE MATERIALS PRODUCED	PRESENT OR FUTURE ACTIVITIES
AAAS Commission on Science Education (AAAS K-16)	John R. Mayor and Arthur H. Livermore/AAAS, 1515 Massachusetts Ave., N.W., Washington, D.C. 20005	American Association for the Advancement of Science/National Science Foundation	Broad Concerns for science education at all levels including curriculum development for grades K-16 and teacher preparation. Sponsors Information Clearinghouse on new projects	Elementary science materials K-5 from a process approach, teacher's commentary, equipment kits for parts 1-4, kits for testing individual processes, and a project newsletter, process hierarchy charts, parts A-G	The Commentary for Teachers was published by Xerox in 1970. The Inservice Program and the Process Measure for Teachers was revised and prepared for publication by Xerox in 1971. An experimental edition of *A Science Process Instrument* was published in 1970. This is a test to be administered to children individually.

PROJECT NAME	ORIGINAL DIRECTOR'S NAME/ PROJECT ADDRESS	SUPPORT: ORGANIZATIONAL/ FINANCIAL	GENERAL PURPOSE	SCIENCE MATERIALS PRODUCED	PRESENT OR FUTURE ACTIVITIES
Biological Sciences Curriculum Study (BSCS)	Arnold Grobman/ University of Colorado, P.O. Box 930, Boulder, Colorado 80301	American Institute of Biological Sciences (1959-63), now University of Colorado/National Science Foundation, Ford Foundation, Asia Foundation, Rockefeller Foundation, USOE	To contribute to the improvement of biological education through the preparation of curriculum materials related to the study of biology	A first course (three versions—10th grade), and BSCS (Second Course), (12th grade), special materials for low-ability students, laboratory blocks, biology teacher's handbook, and numerous supplemental materials for biology teachers and students, BSCS Newsletter	Additional materials are being developed, e.g., for the EMR (Educable Mentally Retarded), ES-70 (Human Ecology—Environmental Biology unit for sophomores), programmed materials and inquiry slides.
Chemical Bond Approach Project (CBA)	Laurence E. Strong/ Earlham College, Richmond, Indiana 47375	No organizational support/National Science Foundation	Design of introductory course in chemistry which emphasizes chemical bonding and chemistry as a process of investigation	Chemistry text, student laboratory guide, teacher's guide, supplementary readings, chart of electronegatives, four self-instruction programs	Project has terminated.

PROJECT NAME	ORIGINAL DIRECTOR'S NAME/ PROJECT ADDRESS	SUPPORT: ORGANIZATIONAL/ FINANCIAL	GENERAL PURPOSE	SCIENCE MATERIALS PRODUCED	PRESENT OR FUTURE ACTIVITIES
Chemical Education Materials Study (CHEM)	George C. Pimental/ Wing B, Gayley Road, University of California, Berkeley, California 94720	University of California and (until 9/63) Harvey Mudd College, Claremont, California/ National Science Foundation	To stimulate and prepare high school students for college chemistry and to give other high school chemistry students an understanding of the importance of science	Chemistry text, laboratory manual, teacher's guide, programmed instruction pamphlets, achievement tests, films, and CHEM Study Newsletter	Project has essentially terminated. Distribution of written materials and films both in English and as translated will be continued. A minimum staff will be maintained to supervise remaining business activities and to carry out contractual obligations. The texbook is available from W. H. Freeman and Company.

PROJECT NAME	ORIGINAL DIRECTOR'S NAME/ PROJECT ADDRESS	SUPPORT: ORGANIZATIONAL/ FINANCIAL	GENERAL PURPOSE	SCIENCE MATERIALS PRODUCED	PRESENT OR FUTURE ACTIVITIES
Engineering Concepts Curriculum Project (ECCP)	E. J. Piel/ The Polytechnic Institute of Brooklyn, 333 Jay Street. Brooklyn, New York 11201	National Science Foundation	Emphasizes the use of "Systems" approach to solving social, personal, political, and environmental problems. Course materials cover fields of science, mathematics, and social science	Text—*The Man Made World*, Laboratory manual, teacher's manual, discussion games, tests, newsletters	Final edition, January 1971. Various conferences on community colleges, Junior High Schools, and Teacher Preparation in 1970-71

PROJECT NAME	ORIGINAL DIRECTOR'S NAME/ PROJECT ADDRESS	SUPPORT: ORGANIZATIONAL/ FINANCIAL	GENERAL PURPOSE	SCIENCE MATERIALS PRODUCED	PRESENT OR FUTURE ACTIVITIES
The Earth Sciences Curriculum Project (ESCP)	William D. Romey/ Earth Science Curriculum Project, P.O. Box 1559, Boulder, Colorado 80301	American Geological Institute/ National Science Foundation	To develop a text, lab manual, and teacher's guide for use in secondary school earth science courses	Earth Science text, laboratory manual, teacher's guide, Reference Series pamphlets, and ESCP Newsletters, Film "Toward Inquiry," Teacher Preparation Packet	ESCP, as a federally funded project phased out in March 1970. The ESCP textbook, *Investigating the Earth* is available from Houghton-Mifflin Company and will be revised under the auspices of the American Geological Institute. Two new projects, the Earth Science Teacher Preparation Project and the Environmental Studies Project were initiated in 1970 and have received financial support.

PROJECT NAME	ORIGINAL DIRECTOR'S NAME/ PROJECT ADDRESS	SUPPORT: ORGANIZATIONAL/ FINANCIAL	GENERAL PURPOSE	SCIENCE MATERIALS PRODUCED	PRESENT OR FUTURE ACTIVITIES
Harvard Project Physics (HPP)	F. James Rutherford, Gerald Holton and Fletcher Watson/ 8 Prescott Street, Cambridge, Massachusetts 02138	Harvard University/U.S. Office of Education, The Carnegie Corporation, The Sloan Foundation, Ford Foundation, National Science Foundation	To develop a new kind of physics course for the science oriented and the science shy, centered on a solid introduction to physics but stressing the humanistic background of the sciences	Six basic text units, teacher's guides, student handbooks, physics readers, laboratory and demonstation apparatus, transparencies, film loops, film strips, tests, programmed instruction booklets, and newsletters	Development of ten additional chapters of the text, instructional film loops, an introductory 16mm film, fifteen additional laboratory experiments, a book of selected readings, tests, programmed instruction, paperback monographs, and laboratory equipment. Materials are available from Holt, Rinehart and Winston, New York.

PROJECT NAME	ORIGINAL DIRECTOR'S NAME/ PROJECT ADDRESS	SUPPORT: ORGANIZATIONAL/ FINANCIAL	GENERAL PURPOSE	SCIENCE MATERIALS PRODUCED	PRESENT OR FUTURE ACTIVITIES
Intermediate Science Curriculum Project (ISCS)	Ernest Burkman, 507 South Woodward Avenue, Tallahassee, Florida 32304	U.S. Office of Education, National Science Foundation	To develop a comprehensive science program for grades 7-9 using computer-assisted instruction as a vehicle for evaluation	Seventh-, eighth-, and ninth-grade textbooks, teacher's guides, tests, additional problems and excursions, response book, answer keys, behavioral objectives, and newsletters	Revision of 9th-grade experimental units, commercial version of 8th grade, Fall 1971; commercial version of 7th grade, Fall 1970
Introductory Physical Science	Uri Haber-Schaim/ Education Development Center, 55 Chapel Street, Newton, Massachusetts 02172	Educational Development Center/National Science Foundation	To develop a one-year course in physical science for use in junior high with an emphasis on student laboratory work	Textbook, teacher's guide, laboratory equipment and apparatus, achievement tests, laboratory tests, films, descriptive brochures	Project has been completed. Materials are available from Prentice-Hall, Inc., Macalaster Sci. Co., and Modern Learning Aids.

PROJECT NAME	ORIGINAL DIRECTOR'S NAME/ PROJECT ADDRESS	SUPPORT: ORGANIZATIONAL/ FINANCIAL	GENERAL PURPOSE	SCIENCE MATERIALS PRODUCED	PRESENT OR FUTURE ACTIVITIES
Minnesota Mathematics and Science Teaching (MINNEMAST)	James J. Werntz, Jr., Professor of Physics, Center for Curriculum Studies, University of Minnesota, Minneapolis, Minnesota 55455	University of Minnesota, National Science Foundation	To produce coordinated mathematics and science curricula for grades K-9; and pre-service and in-service mathematics science and methods courses	Nine units for K-7 science, seven anthology of science units K-7, science methods courses, eight 8mm sound films for science outline and sample units for college science, and MINNEMAST reports	Terminated in 1970. Materials available from W. B. Saunders Co., Philadelphia.
Physical Science Study Committee Advanced Topics	Uri Haber-Schaim/ Physical Science Study Committee, 164 Main St., Watertown, Massachusetts 02172	Educational Services Incorporated/National Science Foundation	Development of advanced topics in physics for use in high school and college physics courses	Five chapters of a text, teacher's guides, laboratory guide, three films, and equipment and apparatus for the laboratory	Project has terminated.

PROJECT NAME	ORIGINAL DIRECTOR'S NAME/ PROJECT ADDRESS	SUPPORT: ORGANIZATIONAL/ FINANCIAL	GENERAL PURPOSE	SCIENCE MATERIALS PRODUCED	PRESENT OR FUTURE ACTIVITIES
Physical Science Study Committee Physics (PSSC)	Jerrold R. Zacharias/PSSC-ESI, 164 Main St., Watertown, Massachusetts 02172	Educational Services Incorporated/National Science Foundation	To present physics as a unified but continuing process by which men seek to understand the nature of the physical world	Physics text, laboratory guide, laboratory apparatus, films, Teacher's Resource Book and Guide, Science Study Series, and PSSC tests	Project has terminated. Materials are available through D. C. Heath Publishing Company.
Secondary School Science Project	George J. Pallrand, 10 Seminary Place, Rutgers University, The State University of New Jersey, New Brunswick, New Jersey 08903	Rutgers University/ National Science Foundation	To develop a program for secondary school grades, centered on geology that will lead students to an understanding of the nature of the earth	Text, student investigation booklets, science reading series, laboratory kit, student record book, teacher folios, tests and examinations, and film loops	Project materials are completed. Teacher training will be continued through the Resource Teachers program. Materials are available through Webster Division, McGraw-Hill Book Company.

*The artistry of teaching science is dependent on how skillfully the teacher blends several of the methods into a unified teaching lesson. The nature of the lesson, the personality and goals of the teacher, the climate of the class, and the interests and needs of the students will determine the ultimate selection and utilization of appropriate teaching methods in science.**

Nathan S. Washton

12

Lesson Planning for Science Teaching

The teacher of science is especially fortunate because of the abundance of things of science which he can use in his teaching. All about him are examples of natural and scientific phenomena. The daily cycle of events, the endless variety of clouds and weather, the growth of plants and animals, the passage of the seasons all contribute to an endless store of materials for scientific discussions. There are rocks and minerals to be collected, flora and fauna in season, and numerous examples of scientific devices to be used as teaching aids in his classes.

An alert and enthusiastic science teacher will not miss the opportunity to use the things of science in his teaching plans. Clever use of appropriate items and examples will inject a degree of interest and spontaneity into his classes which is unmatched by any other method. Students will respond by bringing items for discussion, newspaper clippings, and interesting scientific articles. The spirit of such a classroom will be enthusiastic, exciting, and enjoyable to students and teacher alike. Students will look forward with pleasant anticipation to returning

*Quoted in Ellsworth S. Obourn and John H. Woodburn, *Teaching the Pursuit of Science* (New York: The Macmillan Company, 1965), p. 289.

to class the next day. It is probable that learning will be productive and satisfying.

How does the science teacher put the things of science to use? Are there meaningful ways to plan for effective teaching? Can the teacher maintain sequence and organization and at the same time stimulate interest? Can the objectives of science teaching be realized while permitting the objects of science to dominate the scene? These are questions each teacher must face when planning his yearly and daily work.

The beginning steps in lesson planning should involve much thought before anything is put down on paper. Questions such as "What do I want to accomplish with this lesson?" "What do the students already know about this topic?" "How can I build on what they already know?" "How can I illustrate the main points of the lesson?" must be answered to the teacher's satisfaction before a lesson plan can be prepared.

It is certain that students vary in abilities and interests. Plans must attempt to provide for these variations. Some method of motivating each student must be found. Only by knowing something of the background of each student can the teacher be effective in this task. This presents a strong argument for taking a personal interest in the students in one's classes. The small human contacts in a friendly classroom, an interested question here and there, can achieve this better than any other method.

Circumstances vary, depending on the teacher's purpose; but it is often a good idea to start a lesson with a concrete object or device on which to focus attention. A demonstration or illustration tied in to the main point of the lesson serves as an ideal springboard for discussion and questioning. The stiffness and formality which sometimes accompanies a class period is overcome by this approach, and the class interest is usually high. If the teacher is careful to avoid giving away all the secrets of the device or object, it can become the basis for a problem-solving or inquiry lesson.

An example is given on page 267 of this approach as used in a tenth-grade physical science class which has just finished the study of heat and its effects on expansion and contraction of materials.

The "rubber-band wheel" is set up as shown in Figure 29. A strong light is shone upon one-half of the wheel, and the wheel slowly turns. The question "What makes it turn?" becomes an obvious one to ask. Students who have learned that heated objects expand may come to the conclusion that the rubber bands expand under the strong light, thus throwing off the center of gravity, causing the wheel to rotate. Closer analysis, however, shows that the wheel should then turn in the opposite direction. A genuine problem thus presents itself which should stimulate thinking.

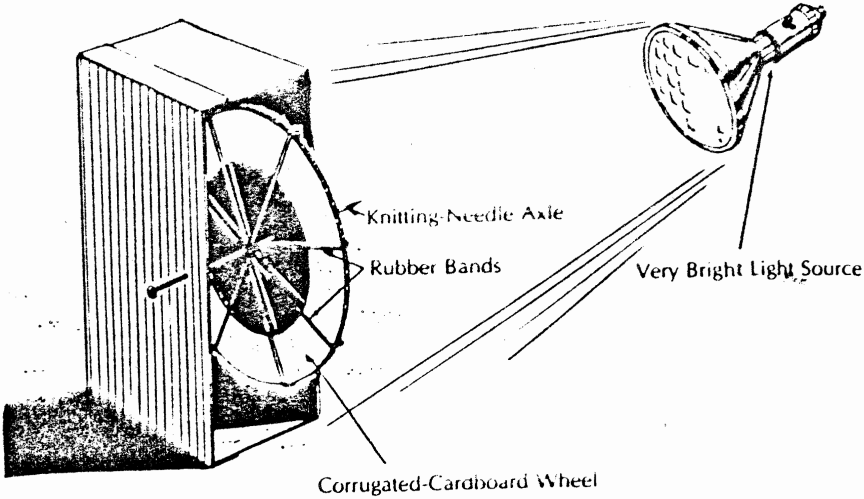

Figure 29

After several ideas are suggested, tested, and discarded, the class may come to the realization that rubber bands under tension contract when heated. This would explain the observed rotation. The correctness of this assumption can be tested by suspending a weight on a stretched rubber band. Heating the rubber band with the spotlight shows it definitely to contract, thus explaining the phenomenon.

With this approach, the teacher begins the class in an interesting manner. Students are encouraged to participate, and an inquiring attitude is stimulated. Students are taught that there frequently are important exceptions to general rules and that one must constantly be on the alert for them.

PREPARING OBJECTIVES FOR SCIENCE TEACHING

Goals and objectives have been discussed in Chapter 5. Their relevance for lesson planning will be discussed in greater detail here. No science teacher should begin a class without a clear idea of where he is headed. Presumably he is in the teaching profession because he wishes to educate young people, to open up new areas of interest, to contribute to scientific literacy and understanding.

To do this, he needs clear goals, clearer and more specific than just, "to teach electricity," or "to develop good citizens," or "to study the lives of great scientists." While these may be worthwhile outcomes to strive for, they are not of assistance in preparing teaching plans. At best, they may point out a direction or an area of concentration. To be truly effective, objectives must prescribe certain student behaviors or changes in modes of action that can be expected as a result of the teaching process. It should be possible to tell when such behaviors have been achieved and, thus, can be evaluated.

In the past few years considerable work has been done on writing behavioral objectives and clarifying various areas and levels of complexity. Three areas—cognitive, affective, and psychomotor—have been identified. The first deals with intellectual, learning, and problem-solving tasks. The second encompasses likes and dislikes, attitudes, values, and beliefs. The third involves skills or proficiencies in the domain of "motor" or "psychomotor" activities.

In the past, cognitive objectives have received major attention. Science teachers have been primarily concerned with knowledge and comprehension of subject matter. Objectives written in these areas have usually been very general and ambiguous. For example, "to understand how an electric motor works" may seem to be a laudable objective for a science class. However, stated in that form, it is too broad and gives little help to the teacher in assessing the student's degree of understanding. How can you measure understanding? What behavioral changes could be expected of a student who "understands how an electric motor works"?

Written in behavioral form, a more useful objective might be, *the student will be able:*

> When shown a diagram of a simple direct current motor, to point out the armature, commutator, field magnet, and brushes.
>
> Or, when given a disassembled direct current motor, to trace the path of the current through the various parts of the motor.
>
> Or, to describe the differences in the wiring diagram for a series-wound and a shunt-wound electric motor.

Each of these objectives spells out some observable behavior which will quickly inform the teacher as to the degree of understanding acquired by the student. In addition to being more specific, such objectives are less ambiguous and more useful in lesson planning.

In the affective area, preparation of suitable behavioral objectives is a more difficult task. Traditional objectives in this area might be something like, "to develop an appreciation of the contributions of great scientist of the past." This objective, of course, is difficult to measure or even to detect. How can the teacher know when such an appreciation has been developed? What kinds of behaviors might give evidence of the achievement of this objective?

While it is impossible to probe inside the student's brain for evidence of such appreciation, there are, nevertheless, certain behaviors one might expect to observe in a student who had developed it. In behavioral form, these might be, *the student will:*

> When given access to a library of science books, voluntarily choose books on the contributions of scientists.
>
> Or, when given the opportunity to choose a report topic, report on the humanitarian contributions of scientists to society.

While these behaviors could not be cited as indisputable evidence that the student had developed an appreciation of the contributions of scientists of the past, one could infer that such activities are indicative of interest and probable growth in this area. As such, the objectives are more useful to the science teacher in planning his class activities.

The psychomotor domain of behavioral objectives involves skill development and growth of certain proficiencies concerned with muscular movements, coordination, balance, strength, and precision. These objectives are useful in science teaching because much of what is learned in science, particularly through inquiry or investigative methods, depends on manipulating apparatus, observing results, making measurements, and recording data. Thus psychomotor objectives are important. A few examples are, *the student should be able to:*

> Cut, fire polish, and bend the appropriate pieces of glass tubing to construct a wash bottle.
>
> Or, adjust the vernier scale of a mercurial barometer to secure a reading accurate to 0.01 inch.

As the science teacher is preparing his plans for teaching, his objectives should be foremost in his mind. They should be more than just hazy generalizations concerning what he hopes to accomplish with his class. It is wise to think through specifically what he desires his students to know or to be able to do at the conclusion of his course. These objectives should be written in behavioral terms and attention given to areas and levels. For example, in the cognitive area, ascending levels of complexity beginning with knowledge and continuing to comprehension, application, analysis, synthesis, and evaluation should be considered.[1] Further discussion of these levels is found in Chapter 13, "Evaluation: Evaluating the Total Person's Behavior."

The task of writing behavioral objectives for one's class is a large one. It is best to work at it while the course is in progress the first year. Gradually a file of behavioral objectives can be built up from which the science teacher can select appropriate ones in succeeding years. Because of the high degree of usefulness in preparing better classroom tests, the completion of the task serves a two-fold purpose—that of establishing less ambiguous objectives and forming an excellent basis for evaluation.

An Instructional Objectives Exchange has been established to assist teachers in selecting and sharing operationally stated objectives for their classes. Inquiries can be directed to:

Instructional Objectives Exchange
Center for the Study of Evaluation
Graduate School of Education
University of California
Los Angeles, California 90024

PLANNING A SCIENCE LESSON

Lesson planning is more than just making sure there is something to do for the entire class period. Unless it is the very first lesson of the year, it is probable that assignments have been made and that the nature of the subject matter is understood. Thus, the basis for planning has already been established.

For the sake of conducting an interesting class period, it is important for the teacher to vary the methods from day to day and even within the class period itself. *It is deadly to fall into the same repetitive pattern of teaching day after day.* Even an excellent method can suffer from overuse. With the great variety of methods to choose from and with the potential excitement of inventing a new technique or modification of one, the science teacher is in an excellent position to plan a highly effective lesson.

> Mr. Foster looked forward to making his plans for the eighth-grade science class on Monday morning. As he thought of the students in his class, it seemed that he might involve them in class participation and generate enthusiasm by doing a demonstration-experiment. The topic for consideration was the explanation of the simple Mendelian ratio of

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[1]B.S. Bloom, M.D. Englehart, E.J. Furst, W.H. Hill, and D.R. Krathwohl, *A Taxonomy of Educational Objectives: Handbook I, The Cognitive Domain* (New York: Longmans, Green Co., 1956).

1-2-1 for the offspring in the first generation produced by the crossing of two pure strains. He would use the crossing of pure white and pure black guinea pigs as a sample case to illustrate this phenomenon.

In pure strains the genes for coat color in the parents could be represented by BB and ww. The only possible combinations in the first generation offspring would be Bw. These animals would be black but each would carry the gene for white. If animals of this genetic makeup were crossed, the possible combinations in their offspring (second generation) would be BB, Bw, wB, and ww.

In order to demonstrate the purely statistical nature of the results obtained in this cross and of the effect of dominant over recessive genes, Mr. Foster decided to make a simple arrow spinner that could be attached to the blackboard with a suction cup. Then a circle could be drawn on the blackboard, around the spinner, and labeled as shown in Figure 30. With this device it would be possible to engage the class in a "game of chance," give them practice in keeping a record of the data, and put across the point of the lesson in an interesting manner.

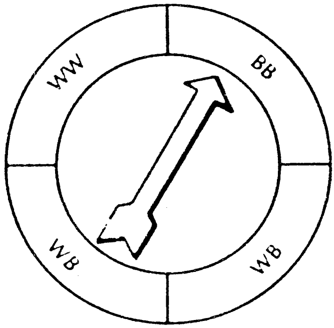

Figure 30

After constructing the spinner, Mr. Foster decided to give it a trial run to see whether it would perform satisfactorily and whether the demonstration could be accommodated in the fifty-minute class period. Out of forty trials, the results he got in his trial run were as follows:

	BB	*Bw*	*wB*	*ww*
Trials:	11	8	11	10

The time required was ten minutes, and the results appeared to Mr. Foster to be sufficiently close to the expected values to illustrate the point. He decided to plan his class period around this demonstration-experiment.

On paper, Mr. Foster's lesson plan looked like this:

Science 8 *Monday, April 20*
Topic: Simple Mendelian ratio
Purpose: To show the statistical nature of the Mendelian ratio
Behavioral Objective:
The student should be able to predict the approximate proportions of each gene combination obtained with 100 trials of the spinner
10 min. Remarks and questions:

1. What is meant by *dominant gene?* By *recessive gene?*
2. Suppose a pure-bred black and a pure-bred white guinea pig (*BB,ww*) were mated. What genes have they for color? What would be the color of their offspring?
3. What are the possible combinations of dominant and recessive genes for color of coat? (*BB, Bw, wB, ww*)
4. What might be the proportions of each of these combinations in the offspring? (1-1-1-1) (Since Bw and wB are the same, the ratios appear as 1-2-1)
5. How would we *show* this to be the result of statistical probability?

Activity: Set up the blackboard spinner. Select a volunteer to spin it. Select another volunteer to keep a record on the blackboard under the headings *BB, Bw, wB,* and *ww* Continue for 10-15 minutes.
20 min. Discussion:

1. What are the actual colors of offspring which have each of the possible gene combinations? (Three black and one white)
2. Why aren't the results in an exact ratio of 1-2-1? (Chance variations when few trials are used)
3. Could we improve the results? (More trials)
4. Student questions (anticipated).

Assignment: A volunteer assignment—two boys or girls might run this experiment for more trials to see what the results would be.
Evaluation:
Time OK? ____ Interest? ____ Understanding? ____

Mr. Foster's lesson plan shows the essential features of a good written plan. The writing of it was preceded by considerable thought regarding purpose and method to be used. The plan itself was concise and brief enough to serve as a working guide. Estimates of the time needed for various activities were made. Leading questions for the discussions were suggested, and some thought was given to the probable questions students might ask. Provision was made for extended work by individuals who might become motivated to pursue it further. Space was left for a note or two regarding the success of the lesson.

It is likely that Mr. Foster will use this idea again at another time. For this reason he will probably file it away for future reference. In modified form it can become a basis for preparing a similar plan for a different class of students at some future date.

Lesson plans should not be re-used in original form year after year. This can only lead to loss of spontaneity and lowered effectiveness. Plans for each year's class should be made anew with an effort toward a creative approach. However, the resources of a past successful lesson can be used for ideas and guidance in planning anew.

PLANNING FOR THE TEACHING TASK IN THE CLASSROOM

Suppose you are faced with the task of planning and carrying out a unit of work in your teaching area for a class you are already acquainted with. What kinds of questions might you ask yourself? How will you organize your thoughts and plans? The following list might serve as a guide:

1. What will be some important factors to take into consideration?
2. How might you involve students in the planning? How much is desirable?
3. What different levels of planning will probably be necessary?
4. What parts of your plans will you, of necessity, put down in written form?
5. What parts of your plans might you prefer to note mentally but not necessarily write down?
6. How much importance will you grant to a time budget?
7. How will you provide for the anticipated questions of the class? For the unanticipated questions?
8. How will you provide for flexibility so that unexpected events can be handled adequately?
9. What purpose will evaluation serve in subsequent planning?
   a. From the standpoint of knowledge acquired by the students?
   b. From the standpoint of modification of the plans for the next teaching?
10. How far in advance should the planning be done? Why?
11. How detailed should your plans be in regard to materials and equipment?
12. What advance preparations may be needed?

13. What follow-up activities may need to be carried out?
14. What probably ought to be done with the plan or plans after the unit has been taught?

A great deal of thought must go into the preparations for teaching. If you can ask yourself the above questions and give satisfactory answers to most of them, your chances of having a successful teaching experience will be greatly enhanced.

THE DAILY LESSON PLAN

Why Plan?

Planning gives direction. For the beginning teacher it is a necessary step in refinement of the art of effective teaching. It enables the teacher to build self-assurance into his classroom presentations. A teacher girded with a well-prepared plan meets his class with forthrightness and confidence. The effect upon the class is usually beneficial. Incipient discipline problems are frequently discouraged; and, most important of all, classroom goals are established firmly, and a plan of action for achievement of these goals is put into effect.

Preparing the Teaching Plan

Thought planning should precede any written plans. Questions such as "Why teach this?" "What good is it?" "How can it be used?" "How can it be demonstrated?" ought to be answered before committing anything to paper. The teacher should have a firm grasp of goals and purposes at this point and be prepared to give justifications, at least to his own satisfaction. He should hold the image of individual students and class character before him at all times, remembering that learning is an individual matter and that no teaching is done unless learning takes place.

The written plan should be concise and functional. The format may vary with the situation and with the individual teacher, but it should be teachable. There should be provision for a listing of main concepts to be taught or skills to be developed. Objectives should be written in behavioral terms. Questions useful as guides to discussion should be noted. Types of anticipated student questions should be listed. All materials needed for the class period should be checked for suitability. Activities and assignments should be noted in sufficient detail to insure a smooth class hour and effective teaching.

Teaching from the Plan

During the class hour, a teaching plan should be as unobtrusive as possible, yet referred to when needed. Main ideas may be memorized and sequence followed, but usually not at the expense of flexibility. As the teacher gains experience. he will be able to extemporize within the framework of the plan and conduct a class period charged with interest and enthusiasm.

Evaluating the Lesson Plan

The experience gained in teaching should be recorded with brief notations on the written plan. This can be done immediately after class, or during the class period if time permits. Suggestions for timing, organization, student reactions, and improvements of a demonstration or other technique can be noted for future use. The modified plan can form the basis for new lesson planning in the future. It should be labeled and filed for future use.

Lesson Plans Guide Your Class

The success of a class period is often directly related to the kind of planning. Good classes in science do not happen by accident. They are the result of meticulous thought, planning, and preparation.

One way to assess the effectiveness of a class is to have it analyzed in terms of student attention.[2] This assumes the degree to which students actively participate or give their attention to the activities of the classroom is to some degree a measure of the class effectiveness. Perhaps it can be considered a rough measure of their learning.

To use this technique, enlist the aid of another teacher or friend to observe your teaching for a full class period. Provide him with a form similar to the following:

OBSERVATION SHEET

Name____________________ Class____________________
Date____________________ Time____________________

Instructions: (a) At intervals of three minutes, count the class and determine the number of students who are actively paying attention to the lesson or activity. Use your best judgment as to whether a student is paying attention. (b)

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[2] Walter Thurber and Alfred Collette, *Teaching Science in Today's Secondary Schools* (Boston: Allyn and Bacon, 1970).

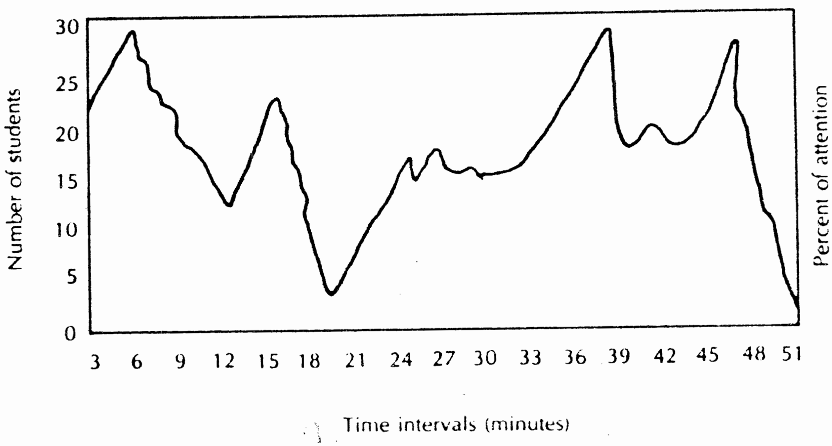
Keep a record of the types of activities engaged in by the teacher and/or class, e.g., lecture, discussion, demonstration, experiment, film, student report, etc. Note the time of transition from one type of activity to another.

Note any major occurrences, such as disciplinary action, public address system coming on, entrance of a visitor, or any unusually distracting event. Plot a graph of percent attention versus time for each class observed.

Total attendance________________

Time	*Class Count*	*Percent*	*Comments*
0	________	_____	____________
3	________	_____	____________
6	________	_____	____________

Following is a class attention record for an eleventh-grade chemistry class of thirty students:



At interval:

3 – Student speaking – asking question.

12 – Group problem solving. Student writing problem on board. No discussion.

15—One of "popular students" answers a question with a witty and correct answer.

18—Instructor opens windows. Thirty seconds of "dead time." Group of five discussing problem.

24—Question-answer discussion with a single student.

36—Student answers question incorrectly. A second student answers same question incorrectly.

39—Instructor begins writing series of problems on the board. Attention picks up.

45—Instructor: "I made a goof." "No, I didn't—Yes, I did—No, I didn't."

48—Preliminary bell rings.

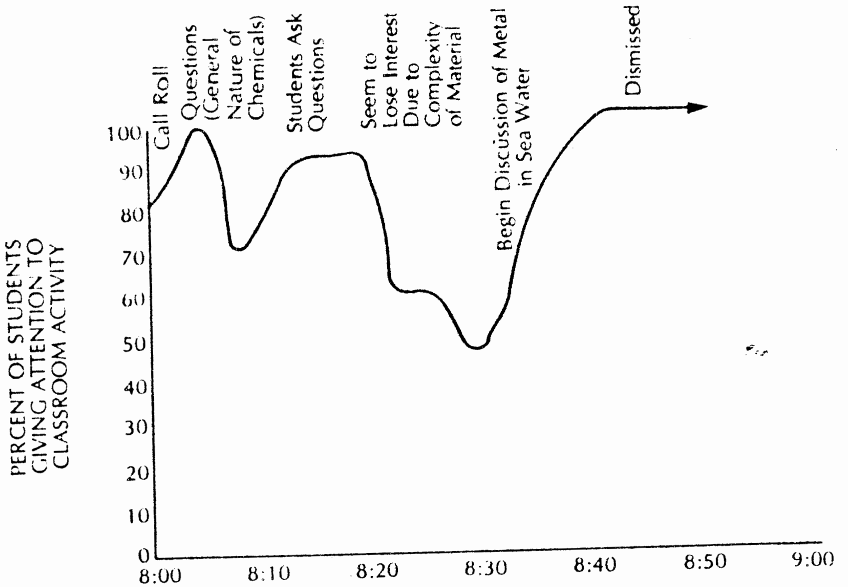
50—Final bell. Five students immediately drop attention in the middle of instructor's explanation.

What accounts for the variability in this class? Why did the class reach such a low point at 18 minutes after the beginning of class? How could the teacher develop sustained interest and attention so that small disturbances such as opening a window would not result in complete loss of attention? There were four points of high attention in this class. From the comments accompanying the graph, can you detect any common characteristics that seemed to elicit high attention? Was it student response, teacher response, distracting events, or other factors?

Following is a series of graphs representing one week of classes in tenth-grade physical science and a composite graph showing the general character of attention in this class for a week. Notice a definite loss of attention near the middle of the class period. What might cause this? Can the teacher avoid this loss of attention by proper planning? What suggestions would you make?

Notice the differences between the classes for Wednesday and Thursday. These were two laboratory days. Why was Thursday's class successful (from the standpoint of attention) while Wednesday's was largely a failure? Was teacher preparation or lack of anticipation of experiment difficulties a possible cause?

Would you say that the graph for Friday represents a highly motivated class? The high points seemed to come for two reasons: (a) when students were actively involved or (b) when students were called to attention by the instructor. How would you plan a similar class to avoid the extreme variability noted here?

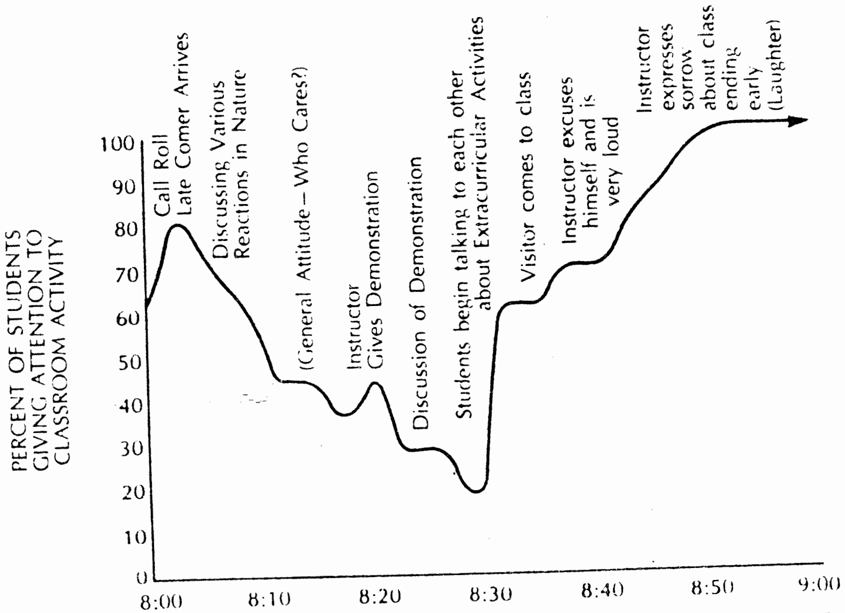


Type of Class—Physical Science

Time – 8:00-8:50
# of Students –12

Activity—Lecture Discussion
(Nature of Chemicals)

Monday

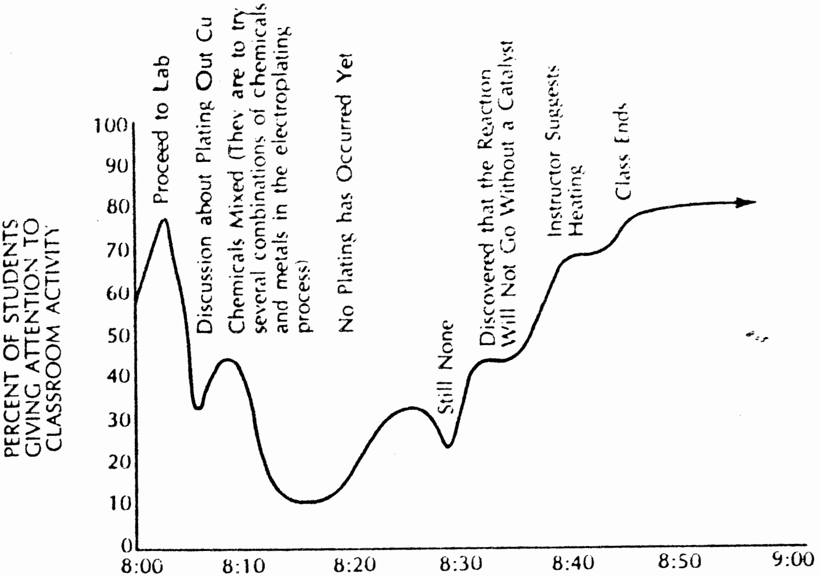


Type of Class—Physical Science

Time – 8:00-8:50
# of Students – 11

Activity—Discussion (Various Types of Reactions)

Tuesday

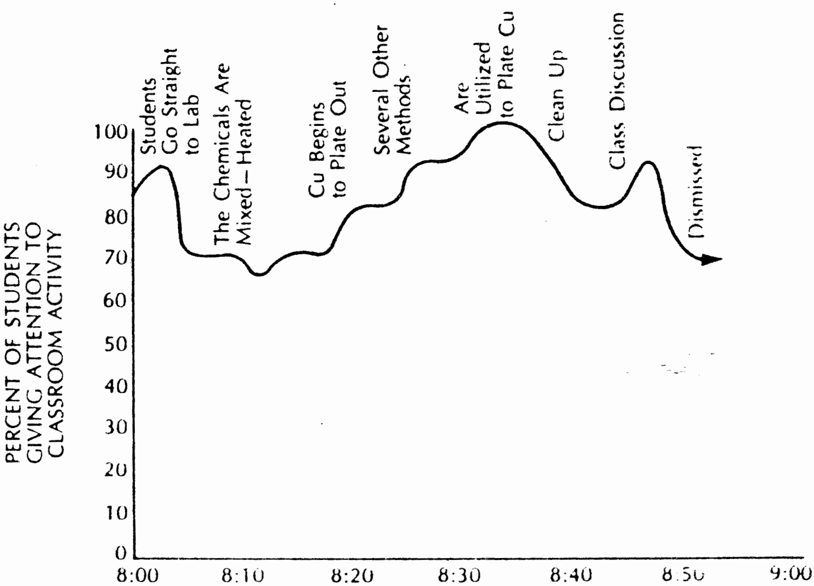


Type of Class—Physical Science

Time—8:00-8:50
# of Students—9

Activity—Lab (Electroplating)

Wednesday

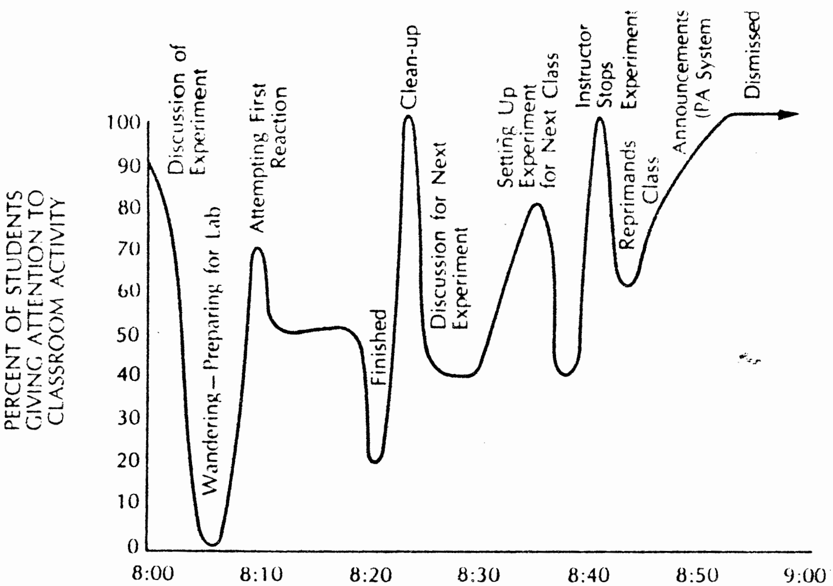


Type of Class—Physical Science

Time — 8:00-8:50
# of Students—11

Activity—Lab (Reactions)

Thursday

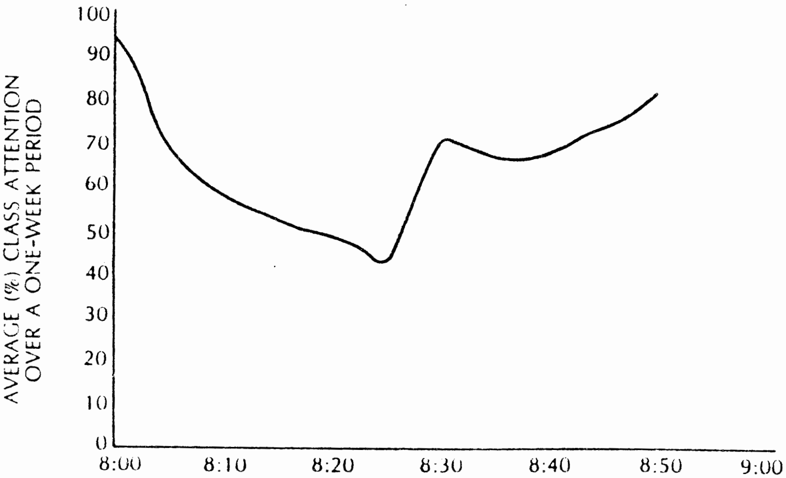


Type of Class—Physical Science

Time — 8:00-8:50
# of Students—10

Activity—Laboratory Experiments on Chemical Activity of Various Metals

Friday



Composite Graph Shows the General Trends of Classroom Attention in a Physical Science Class

The Long-Range Lesson Plan: An Illustrative Case

Miss Henderson was a new teacher of tenth-grade physical science at Warren High School. The head of the science department, Mr. Longwell, who had taught the course the previous year, had talked briefly with Miss Henderson concerning the objectives and general nature of the course.

No textbook was being used. Mr. Longwell believed that most physical science textbooks attempted to cover too many topics in a one-year course. In order to permit time for greater depth of study, only five major areas were taught in physical science at Warren High; these were the nature of the atom, the nature of the molecule, nuclear energy, radiant energy, and man's applications of physical science. Materials for the course were provided by mimeographing and by the purchase of small paperback books on appropriate science topics.

On discussing the objectives of the physical science course, Miss Henderson and Mr. Longwell agreed that it should serve a dual role—to introduce students to the more rigorous specialized chemistry and physics courses in the eleventh and twelfth grades of Warren High School and to function as a terminal science course for those students who were planning to go into nonscience areas of study. The attempt was made to approach the chosen topics from an activity and laboratory point of view as much as possible.

With this background of understanding of the course, Miss Henderson decided to outline the year's work. Her first task was to plan the sequence of topics. She decided that the sequence used by Mr. Longwell—atom, molecule, nucleus, radiations, applications—had stood the test of experience and seemed to be a logical sequence; therefore, she would use this sequence the first year and modify it in the future if necessary. With only five areas to study, it seemed feasible to plan about six weeks on each of the first three topics and eight weeks on each of the last two. This would enable the class to finish the third topic at the end of the first semester. Miss Henderson realized that this schedule might have to be modified, but she was prepared to make the necessary adjustments when needed.

Over the next few days, other parts of the long-range plan were put into place. Films were ordered to arrive at the proper times—as nearly as could be estimated so early in the year. Dates of holidays and examination periods were considered. Some thought was given to a possible excursion or two during the teaching of the final topic, on applications, but the dates were left tentative. The storage room was checked for apparatus and laboratory supplies and seemed adequate, but Miss Henderson knew certain unavailable materials might be needed on short notice. She checked with Mr. Longwell and found that expendable items could be obtained within a week from a laboratory supply house.

Miss Henderson kept a loose-leaf planning notebook for each of her classes. The long-range plan and schedule was placed in the front of this notebook, and space was allotted for notes and modifications.

The Teaching Unit

A beginning teacher can be assisted by a teaching-unit plan which is designed in moderate detail for a period of a month or six weeks. The unit topic is usually a cohesive area of study which fits into the long-range plans and objectives. The teaching unit frequently contains the following sections and characteristics.

1. Objectives
2. Content
3. Methods
4. Materials
5. Evaluation
6. Teaching Sequence

The objectives ought to be brief statements of purpose for the unit. They should serve as constant reminders to the teacher of the things to be accomplished in the time allotted. They should be practicable, timely, and carefully suited to the capabilities of the class. Statements of platitudes, characteristic of some objectives lists, should be avoided. Objectives should be testable and written in behavioral form.

Content refers to the actual subject material to be taught in the unit. Because this may be voluminous, the teaching-unit plan cannot list all of it in minute detail; however, the plan may list major principles, pertinent facts of major importance, examples and illustrations, and references to specific knowledges in text material deemed important for the unit. An outline form may be used in this part of the unit plan. Because of the chronological nature of the teaching unit, specific content and references to subject matter can be distributed in a sequential manner throughout the unit.

Methods and procedures to be used in teaching should be planned as carefully as possible. Certain parts of the teaching unit may be taught more suitably by one method than by another. For example, an appropriate film may be the most effective teaching agent for a particular subtopic. Another time, individual work in the laboratory may be the best way to achieve the teaching objectives. At still another time, discussion of a problem by small groups within the class may be the best mode of teaching.

A teacher of science must constantly be on the alert for more effective teaching methods and must guard against stereotyping his teaching. Careful planning of the teaching unit can achieve the proper balance and variety for a stimulating class experience. Materials must be planned with care in order to insure their availability at the time they are needed. In some cases, ordering is necessary a few weeks in advance. Apparatus should be checked to see if it is in working order. Development of the teaching unit will undoubtedly involve several hours work in the library, getting ideas for reading materials and activities. Consideration should be given to the needs of slow and rapid learners, and suitable materials should be arranged for these students. If mimeographed materials are to be used, arrangements must be made for preparing, typing, and duplicating these materials.

Evaluation should be thought of as a continuing process throughout the study of the unit. One of the major functions of evaluation is to keep students informed of their progress and to give them realistic assessments of their own abilities. The use of assigned work, short quizzes, conferences, and unit tests must be planned in the teaching unit. Not all of the evaluative devices and techniques can be planned in detail in advance, but provision for their use can be incorporated. Evaluation should be based upon the objectives of the unit.

The teaching sequence may be outlined for the period of time involved, but flexibility for change must be provided. This can be done by arranging for alternative procedures, omission or addition of certain subject matter, provision for unplanned periods interspersed occasionally to take up slack or give needed time for completion of a topic.

The teaching unit should be thought of as a guide for action rather than a calendar of events. Slavish attention to the preplanned schedule can result in ineffective rigidity. On the other hand, reasonable attention to the sequence, objectives, and procedures of the teaching unit can promote better learning and feelings of satisfaction and accomplishment when it is finished. A sample format for a teaching unit on the topic of nuclear energy follows:

Teaching Unit on Nuclear Energy

Class: Physical Science 10

Period: December 1-January 24

Long-range goals:

1. Present current information on structure of the nucleus.
2. Teach methods used in obtaining nuclear energy.
3. Show applications of nuclear energy to peacetime uses.
4. Develop responsible attitudes for control and use of nuclear energy.

Dates (Tentative)	*Topic*	*Materials and Activities*
	1. Introduction	Resource people
	2. Behavioral objectives	Films and filmstrips

Dates (Tentative)	Topic	Materials and Activities
	3. Science principles	Experiments
	4. Skills to be taught	Demonstrations
	5. Facts and concepts	Projects (student)
	6. Attitudes and appreciations	Field trips
	7. Generalizations	Committee work
		Assignments
		Tests and quizzes
		Open houses
		Resource books
		Periodicals
		Charts

Checklist of Requirements for the Science Unit

The following sections should appear in your teaching unit in the order indicated below. After completing the unit, place this form at the front of the unit just after the title page and mark a check in the spaces provided on the left margin to indicate you have checked to see that you have included all of the sections.

____ 1. *Title Page.* Give the title of the unit, grade level and whether it is based on some new curriculum. If it uses a modern curriculum, state the name of the curriculum. List your name, the title and number of the course, and leave a space for the unit evaluation.

____ 2. *Objectives.* These should be stated preferably in behavioral terms.

____ 3. *Weekly Schedule of the Unit.* A brief one-page survey of what will take place each day as shown below.

a. Include reading assignments

b. Include homework activities

Class Activities	*Home Activities*
Monday	Monday
Study the Aquarium	Collect insects
Tuesday	Tuesday
Compare the difference among insects and where they are found	Collect more insects and study what they eat

___ 4. *Laboratory Exercises.* These should be some of your own laboratory activities including the following:

   a. The subject matter objectives (concepts) the lab will teach.

   b. Critical thinking and problem-solving processes the lesson will develop, indicated in the margin of the activity.

   c. A discussion section preceding the lesson and open-ended possibilities following the lesson.

___ 5. *Invitations to Inquiry.* (These are to be prepared by you) Indicate the processes you are trying to develop in the margin.

___ 6. *Discussion Questions During or at the End of the Unit.*

   a. List the questions you will ask to determine whether the children understood the material studied and if they can apply what they have learned.

   b. The questions should, where possible, attempt to develop critical thinking and problem-solving processes. The type of mental process the student has to use, for example, predicting or inferring, should be placed in the margin to indicate what is required.

___ 7. *Pictorial Riddles.* The pictures or diagrams for these should be included. Place under these the questions you will ask.

___ 8. *Demonstrations.* Include only if they are required because of a shortage of equipment or examples of the safety reasons.

___ 9. *Bulletin Board Display.* Prepare a diagram for at least one bulletin board display indicating how it will appear.

___ 10. *Supplemental Materials You Might Want to Use.*

   a. Laboratories or investigations

   b. Reading materials

___ 11. *Audio-Visual Materials You Might Use.*

   a. Films

   b. Film loops and film strips

   c. Audio-tapes

   d. Transparencies

   e. Models, charts

___ 12. *Consideration of Safety Precautions.* What, if any, special considerations should be made about safety?

___ 13. *Reference or Resource Materials.* Include magazine materials and books you might want to use to improve your knowledge about the topic. These may include teacher's manuals.

3. List of activities and projects, with brief plans for carrying them out
4. Suitable demonstrations and experiments—ranging from simple to complex
5. References and source books
6. Tests and other evaluative materials
7. Lists of films, filmstrips, slides, transparencies, charts, models, and other visual aids
8. Bibliographies for student reading and teacher reference
9. Miscellaneous teaching aids, study guides, free and inexpensive materials, etc.

Construction of a good resource unit is a task which is never entirely finished but which can lead to improved science teaching year after year. The resource unit must be updated periodically in the same way in order to keep it effective for lesson planning.

A sample abbreviated resource unit is reproduced below:

Resource Unit on The Nature of the Atom

Class: Physical Science 10 — Warren High School

Period: September 15 - November 1 — Number of students: 24

Major Goals of the Unit:

1. To learn the structure of the atom and historical development of present understandings of the atom
2. To learn the symbols for the elements and the basic information of the periodic chart
3. To learn to write formulas and equations for chemical reactions
4. To perform the basic chemical reactions in the laboratory
5. To learn some applications of chemistry to the work of the world.

Important Cognitive Objectives. Student should be able to:

1. Define atoms and molecules.
2. Write the symbols for thirty of the most commonly used chemical elements.
3. Explain the significance of the rows and columns of the periodic chart.
4. Explain the meaning of valence and give the valence of ten common elements and ions.
5. Describe the activity series and its usefulness.
6. List the common rules for naming compounds — acids, bases, and salts.

7. List the rules for writing chemical equations.
8. Describe four basic chemical reactions.
9. List the rules for balancing simple equations.

Important Psychomotor Objectives (Laboratory). Student should be able to:

1. Demonstrate the use of safety procedures in the laboratory.
2. Recognize and assemble basic laboratory equipment.
3. Use the trip balance correctly.
4. Observe and describe chemical reactions taking place in a test tube.
5. Record data neatly in a laboratory notebook.
6. Graph data to show relationships.
7. Use the *Handbook of Chemistry and Physics* effectively.
8. Clean and store glassware and apparatus properly.
9. Exhibit proper laboratory techniques.
10. Write a clear laboratory report.

List of Activities and Projects:

1. Learn the sources of the names and symbols for the elements. What revisions in naming the elements have taken place in recent years?
2. Compare the short form and the long form of the periodic chart. What are the advantages and disadvantages of each?
3. Construct models, using suitable objects such as Tinker Toys, rubber stoppers, gumdrops, toothpicks, etc., of several common compounds (e.g., H_2O, CO_2, NaCl, NH_3, etc.)
4. Design a large chart showing the chemical processes involved in smelting of iron, or production of sulfuric acid.
5. Prepare the materials for a bulletin-board display on one of the following topics:
   a. Naming of chemical compounds
   b. Atomic diameters
   c. Types of chemical bonding
   d. Four basic chemical reactions
   e. An industrial process using chemistry

Experiments and Laboratory Exercises:

1. Familiarization with laboratory equipment
   a. Names and identification of:
      1) Ringstand
      2) Bunsen burner
      3) Beaker
      4) Florence flask
      5) Erlenmeyer flask
      6) Test tube and test-tube rack
      7) Igniter
      8) Trip balance

9) Crucible
10) Mortar and pestle
11) Test-tube holder
12) Burette clamp
13) Other common items

2. Safety materials and procedures in the laboratory
   a. Laboratory aprons
   b. Laboratory goggles
   c. Heating a liquid in a test tube
   d. Lighting the Bunsen burner
   e. Handling and pouring acids
   f. Pouring acid into water
   g. Use of the trip balance
   h. Labeling reagents
   i. Emergency procedures in events of accidents
   j. Other safety precautions
3. Preparing and assembling glass tubing and glassware
   a. Procedures for working glass tubing
      1) Cutting
      2) Fire polishing
      3) Bending
      4) Drawing a capillary tube
      5) Sealing a glass tube
   b. Assembly of a simple apparatus using glassware, e.g., a wash bottle
4. Representative chemical reactions
   a. Composition or synthesis
      1) $Fe + S \rightarrow FeS$
   b. Decomposition
      1) $2KClO_3 \rightarrow 2KCl + 3O_2 \uparrow$
   c. Replacement
      1) $Fe + CuSo_4 \rightarrow FeSo_4 + Cu \downarrow$
   d. Ionic
      1) $Ag^+ + Cl^- \rightarrow Ag^+Cl^- \downarrow$
5. Volume determination of a gas by water displacement
   a. Manufacture hydrogren by replacement with zinc in hydrochloric acid.
      Capture the gas in an inverted container by water displacement.
      Measure the volume of the displaced water.
      1) Under what conditions will this equal the volume of the gas manufactured? How can you achieve these conditions?
6. A simple qualitative analysis experiment using an unknown compound
   (details to be worked out after students have done the preceding experiments)

References and Source Books:

Teacher

1. Chemistry textbooks
   a. *Modern Chemistry*, Holt, Rinehart & Winston
   b. *Chemistry, An Investigative Approach*, Houghton-Mifflin
   c. *Chemistry: Experiments and Principles*, Raytheon Education Co.
   d. *Chemistry, An Experimental Science*, CHEM Study, W. H. Freeman
   e. *Chemical Systems*, *CBA*, McGraw-Hill Book Co.
2. Resource books
   a. *A Sourcebook for the Physical Sciences*, Harcourt Brace Jovanovich
   b. *Chemistry Problems*, Holt, Rinehart & Winston
   c. *Scientific Experiments in Chemistry*, Holt, Rinehart & Winston

Student

1. *How To Do an Experiment*, Harcourt Brace Jovanovich
2. *The Chemical Elements*, Science Service
3. *Science Projects Handbook*, Science Service
4. *Handbook of Chemistry and Physics*, Chemical Rubber Company
5. *Welch Vest-Pocket Chart of the Atom*, (classroom supply) Welch Scientific Company

Tests and Evaluation Materials:

1. Quizzes
   a. Symbol-identification quiz
   b. Quiz on naming acids, bases, and salts
   c. Quiz on types of chemical reactions
2. Practical quiz on laboratory work
   a. Naming of items of laboratory equipment
   b. Laboratory-procedures quiz: weighing, glass working, use of chemical tables
3. Unit achievement test
   a. Twenty multiple-choice questions. (Any, all, or none of choices may be correct.)
   b. Twenty completion questions
   c. Twenty modified true-false questions
   d. Five short-answer essay questions

Lists of Audio-Visual Materials:

1. Films
   a. *Chemical Families*, Modern Learning Aids, New York, 22 minutes, color

   b. *Chemical Reactions*, Edited Pictures, 20 minutes, black and white
   c. *Molecular Motions*, Modern Learning Aids, 13 minutes, color
2. Models
   a. Student Molecular Models, O. H. Johns Glass Company, Ltd., Toronto, Canada
3. Charts
   a. Periodic Chart of the Elements, Welch Scientific Company
   b. Chart of the metric system

INSTRUCTIONAL TECHNIQUES

It is important to have in mind a variety of teaching techniques and possible classroom situations that might call for specific techniques. To assist the science teacher in selecting these, a list of possible situations which he might encounter in his daily teaching is suggested.[3]

Situations Requiring a Variety of Techniques:

Applications

1. A student has brought to class a newspaper clipping of a current scientific event. You decide that it is applicable to the material being studied and use it as a teaching situation.
2. You wish to use an everyday application as a review of key ideas previously taught.
3. You wish to make your course particularly functional by relating it to a "do it yourself" experience.

Appreciations

4. You wish to bring about the realization that we have not exhausted the unsolved problems in science. On the contrary, the more we know the more we realize how much is still to be learned.
5. You wish to develop an appreciation for the work of scientists in the past.
6. You wish to apply scientific concepts just acquired to the home situation with particular emphasis on how lack of knowledge often leads to wrong or inadequate solutions.

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[3]Courtesy of Lawrence Conrey, "Instructional Techniques" (Unpublished materials, University School Ann Arbor, Michigan, 1961).

7. You wish to relate scientific knowledge developed in class to intelligent consumer buying, preferably of products that a teen-age person would purchase.
8. You decide to try to develop in the group the appreciation for a truly unusual scientific phenomenon.
9. You decide to try to orient the group to an appreciation for the rapid advances of scientific knowledge through consideration of what new things the text might contain for students taking the course ten years from now.

Attitudes

10. You wish to develop the proper attitude toward thorough observation and proper interpretation of what is observed.
11. You wish to guide the group in developing a sensible attitude toward those scientific problems or situations for which there is not, as yet, a definite answer.

Demonstrations

12. A demonstration experiment has just failed, as far as producing the desired scientific results. You are to make the most of the learning situation that this failure provides.
13. You wish to teach the proper method to use a scientific device.
14. You wish to demonstrate how the proper problem-solving approach can be used to answer a "why does it work" type of question.
15. You wish to make the teaching of a scientific principle more functional by demonstrating or describing several everyday applications of the principle.
16. You wish to demonstrate a new scientific principle in a simple manner which the students themselves can try out at home or show their parents.

Individual Differences

17. You wish to make a genuine effort in adjusting to individual differences by teaching one concept so that the slowest person will understand it and yet the most capable one will not be bored.
18. You wish to familiarize students with new vocabulary at the beginning of a unit and attempt to convince them of the need for correct knowledge of new words.
19. You wish to emphasize the opportunities available in science careers in a manner that will appeal to high school students who are weighing these important vocational decisions.

Knowledge

20. You wish to orient the students to the first unit of the course.
21. You wish to correct a prevalent misconception.
22. You wish to place an idea or concept in a more concrete setting so that it will be more readily understood.
23. You wish to develop in the students an understanding of the fact that our ideas of what is "true" change as we gain more knowledge.
24. You wish to bring about the realization that through functional knowledge of a principle, we can group together many everyday applications that would not seem to be related at first glance.

Methods

25. You wish to emphasize the dangers of quick decisions without sufficient supporting evidence.
26. You wish to use the inductive approach to the teaching of a scientific principle.

Review

27. You wish to conduct a drill experience but at the same time use a technique that will be enjoyable for the students.
28. You wish to use an instructional game as a means of developing new learning or review, or to lend variety to the class instruction.
29. You wish to give a demonstration using "common gadgets" as a means of review of material previously taught.

Techniques Useful in Introducing New Material:

Current Events

1. Coordination with a timely natural event or phenomenon. Examples: tornado, eclipse, seasonal effects, sun "dogs," hail storm meteor shower, earthquake, flood, northern lights.
2. Use of timely newspaper clipping or magazine article on the subject matter of the unit.

Demonstrations

3. A series of demonstrations with scientific or simple everyday equipment for the purpose of stimulating the class, with answers to be sought later.

4. "Bottle in the box" technique to indicate to the student what the steps are in problem solving and to identify several of the important scientific attitudes.
5. A "problem-solving" demonstration which points out the areas where factual learning or knowledge of principles must take place before an explanation for the experiment can be achieved. This experiment could be one involving home "gadgets" or appliances.
6. Set up a laboratory gadget, useless machine, model of one of the body systems, or other device to provoke questions and stimulate interest.
7. Conduct a "silent demonstration," asking students to observe carefully, and follow it by a series of questions to ascertain the correctness of their observations and conclusions.

Outside Resources

8. A community survey of resources or the manner in which certain community problems are handled.
9. An "accumulation" field trip to acquire natural objects (rocks, flowers, fossils) which will be used in instruction to follow.
10. A collecting assignment to assemble items of home equipment so that students will have their own "equipment" to do experiments in connection with the unit.
11. A library assignment to become acquainted with the resource materials available on the topic to be studied.
12. "Inquiring reporter" technique. Students are instructed to ask a specified number of adults some question based on the unit. These answers can then be checked in reference books and discussed in class.
13. A talk by a parent or friend from the neighborhood. Devise questions in advance to ask him.
14. A visit to a factory, farm, or business place connected with the area to be studied.

Questioning

15. Introduction of thought-provoking questions to serve as orientation to the areas of new material to be covered, e.g., "Light." Examples:
    a. Where does the light go when it goes out?
    b. Why is the sky blue?

c. Have you ever seen anything that wasn't there?
d. Why do stagecoach wheels often go backwards in moving pictures?
e. Why is the rainbow curved?
f. What color is a red dress in green light?

16. A film. Prior to the showing the students might be given three or four questions which would be answered by close observation of the film.
17. A problem situation with the question, "What would you do if . . .?" Examples:
    a. What would you do if you found it necessary to move a rock ten feet and you were not strong enough to roll it or lift it?
    b. What would you do if the person next to you suddenly fainted?
    c. What would do if your life depended on devising a means of communicating with someone twenty miles away?
18. Reading assignment in text followed by question-answer period.
19. A collection of questions raised by the class based on their own experiences which they would like to have answered by study of the unit.

Student Initiative

20. An individual experience in the laboratory to "discover" new information and to answer a series of questions about the laboratory experience which will require some reasoning.
21. Group study technique in which each group decides what area it wishes to investigate and report back to class.

Miscellaneous

22. The use of a phrase or a picture which contains important or common errors as an exercise in careful observation.
23. Introduction of a common saying or superstition and deciding with the students what scientific information must be determined before a person can decide whether the saying or superstition has any basis in fact.
24. Written pretest to ascertain background of basic facts and concepts acquired prior to the start of the unit.
25. Presentation of a science puzzle, the answers to which will be filled in as study of the unit progresses.

Techniques Useful in Review or Re-Emphasis:

Demonstrations

1. "What is wrong with this display?" Several arrangements containing basic errors are set up at various stations. Students move from station to station attempting to identify all the errors.
2. "What is wrong with this?" A demonstration performed by the teacher; this can be particularly effective for a procedure such as weighing, using a microscope, making a chart or diagram, etc.

Discussion

3. A teacher-directed discussion in which particular emphasis is placed on questions missed on previous examinations.
4. A teacher-directed discussion in which only answers are given to questions formulated by the students. This places emphasis on and gives opportunity for student questions.
5. Teacher-directed discussion period stressing the facts and principles considered important.

Instructional Games and Puzzles

6. Crossword or "maze" puzzles prepared by students and worked out by other students on an exchange basis. These afford the opportunity to place emphasis on spelling, vocabulary, and definition of terms.
7. Instructional review games such as "Twenty Questions," "Charades," "Spelldowns," and "Puzzles."

Miscellaneous

8. A set of review questions prepared either by the teacher or by students to ask other students.
9. "What is wrong with this thinking?" Teacher reads an explanation or several explanations of fundamental principles of the material just covered and the students attempt to identify all the errors.
10. A film with careful follow-up of the important material it contains.

LESSON PLANNING FOR TEACHING BY INQUIRY METHODS

Recent developments of new courses in secondary science have brought new emphasis on inquiry and discovery methods in the classroom. The typical teacher of science may be hesitant about using these methods because of lack of familiarity with them and because his own training may have emphasized other classroom procedures. He may have had little experience working in classrooms in which the responsibility for learning rests primarily with the individual student.

Lesson planning for the "discovery classroom" presents certain unique problems. To assess these problems, it may be helpful to consider a laboratory lesson of the open-ended type and to identify at the outset the characteristics of this type of experimentation.

The Manufacturing Chemists' Association has identified a number of features of the open-ended experiment as follows:

1. The experiment asks a broad question—the design of the method is frequently left up to the student.
2. The student generally does not know the answer to the question before doing the experiment.
3. The student must thoroughly *understand* the problem, the *reason* for the problem, and the possible *methods* to be used to solve the problem.
4. The student makes his own observations and draws his own conclusions.
5. The write-up of the experiment should be a written statement of the purpose of the experiment, the data, and the conclusions drawn.
6. The open-ended experiment requires more thinking on the part of the student to interpret what he observes and determines.
7. The data may be interpreted on many different levels of student ability.
8. The answer to the problem posed in the experiment can lead to new problems, which in turn can act as bases for further experimentation and discussion.
9. The experiment is adaptable to laboratory periods of varying length.
10. The student does not ordinarily know in advance the result to expect.
11. The student may in some experiments contribute his result to a class result, and it can become a matter of pride that his contribution to the group result is accurate and significant.
12. There frequently is no one "right" answer to the experiment. Each student has to find out for himself the right answer for his own apparatus.

13. The experiment may cause students to see that many searching questions can be centered upon a single experiment and that an experiment should be observed and questioned from every viewpoint.
14. The student may investigate some properties and on the basis of these properties may be asked to make an explanation which accounts for the properties.
15. The student may be asked to reach a generalization from data which he has collected and to use this generalization to predict the behavior or experimental result of a related experiment.
16. The experiment may initiate a problem for further investigation at home or after school.[4]

It is apparent that students in the discovery laboratory are given much more responsibility in planning experiments and carrying them to completion than has traditionally been the case. Effective handling of this responsibility will depend largely on how well the science teacher can provide experiences that will develop students capable of designing experiments, gathering data, and drawing conclusions from them.

Planning for such experiences should be done with the following points in mind:

1. Students probably have not had many previous opportunities of this type. Some may feel the need for explicit directions because this is what they are used to. The initial progress made by these students may be disappointing and frustrating, both to student and teacher.
2. Acceptance of responsibility for one's own learning is a challenge which some students may tend to resist. Passive learning in which the teacher has been the key person for initiating a course of action has probably been ingrained in the student's background.
3. First attempts should be on a small scale, with opportunities for greater choice and greater responsibility increasing as the student gains experience.
4. Rather than acting as a dispenser of information, the teacher should provide situations in which questions are asked. The student should be encouraged to formulate and ask questions—of

[4]Manufacturing Chemists' Association, *Scientific Experiments in Chemistry* (New York: Holt, Rinehart & Winston, 1962).

himself, of the experiment, of resource persons, and of library resource materials.

5. Experience in analyzing the results of an experiment must be provided. The ability to see relationships, to organize data so that meaningful patterns emerge, to draw inferences, and to visualize ways of improving the experiment is a necessary skill which must be developed for effective learning by the inquiry method.

An example of a laboratory experiment which can lead to training in inquiry and discovery is the monolayer experiment for determining the size of a single molecule. In this experiment the student is given a minimum of instructions and is encouraged to devise techniques to arrive at a satisfactory result. A lesson plan for this experiment might look like this:

Class: Physics 12 Section: 9:00 A.M.
Date: November 12
Topic: Calculating Avogadro's Number—Laboratory Experiment
Aims:
The student should be able to:
1. Measure the size of a molecule of oleic acid.
2. Devise suitable techniques for measuring an extremely small length.
3. Recognize the use and limitations of scientific assumptions.
4. Calculate Avogadro's number.

Procedures:
1. Distribute mimeographed copies of guides for the experiment the day before.
2. Allow students to choose partners and work in groups of two.
3. Have students draw the necessary materials from the stockroom. Insist on clean-up and return of all items at end of class period!

Materials:
1. Twelve ripple tank trays
2. Twelve monolayer kits (oleic acid, alcohol, eyedropper, 10 milliliter graduate)
3. Lycopodium powder
4. Twelve large beakers

References:
1. PSSC, *Physics*, D. C. Heath & Company, p. 118
2. Lehrman, *Scientific Experiments in Physics*, Holt, Rinehart & Winston, p. 54
3. "Molecular Constants," *Handbook of Chemistry and Physics*, Chemical Rubber Company

Evaluation of Lesson Plan:

1. Sufficient time? ____
2. Instructions adequate? ____
3. Results of experiment all right? ____
4. Reports all right? ____

The mimeographed instruction sheet to be distributed to students to guide them in performing the monolayer experiment might be as follows:

Instruction Sheet

Physics 12 Date: November 12

Name: ______________________________

Experiment No. 6 Calculating Avogadro's Number by Use of the Monolayer

General Instructions:

Your purpose in this experiment is to employ a monolayer of stearic acid or oleic acid to determine the size of a single molecule of an organic acid and from the measurements obtained to calculate Avogadro's Number. There are several basic assumptions you will have to make, and your results may be expected to be quite satisfactory if they are within an order of magnitude of the accepted value. The main point of the experiment is to learn a technique for obtaining a measurement of something very small and to recognize the limitations of the method. A second point is to obtain a clearer understanding of what Avogadro's Number is and how it can be calculated directly.

Materials Needed:

1 ripple tank tray or suitable substitute at least 18 in. by 18 in.
Oleic acid or stearic acid
Methyl alcohol for dilution
1 eyedropper
1 graduate (10 ml. preferably)
1 large beaker
Lycopodium powder or chalk dust

Suggested Procedures: (Answers to questions are given to assist the teacher in planning)

1. One drop of pure oleic or stearic acid will be too concentrated. It will need to be diluted about 1 to 200 or 1 to 400 with methyl alcohol. What effect will the alcohol have on the experiment? (It will assist in spreading the oleic acid on the water surface but will not affect the final results.) What will probably happen to the water surface? (Being highly soluble in water and volatile as well, the alcohol will probably dissolve in the water or evaporate quickly.)
2. You will need to know the volume of one drop of the oleic acid-alcohol solution. How can you measure the volume of one drop?

Remember greater accuracy can be achieved by getting the volume of many drops and taking an average. (Count the drops required to fill one cubic centimeter in the graduate.)

3. When you put a drop of solution on the water surface, what kind of geometrical figure will it assume? (Cylindrical.) What is the formula for volume of such a figure? (Vol.$=\pi r^2 h$.) To find the height of this figure, what information do you need? (Volume of the drop and radius of the circle.) What assumption may you be making here? Is it a reasonable assumption? (You are assuming that the layer is just one molecule thick.) How could you test the validity of this assumption?

   (Compute the area of the circles formed by one drop, two drops, three drops, etc. You will find the areas approximately double and then triple with the second and third drops. This supports the idea that the oleic acid spreads out to a layer just one molecule thick and does not "pile up" in the center of the circle. The only other conclusion is that oleic acid molecules always come in multiples of one drop—a conclusion not justified by other observations.)

   If the assumption is not valid, what kind of conclusion can you draw from your final result? (The final result will give a value which is too large.)

4. What effect may the lycopodium powder or chalk dust have on the diameter of the circle produced by the drop of oleic or stearic acid? (It may restrict the free spread of the acid on the water surface.) How can this effect be minimized? (By using just a *very* small amount of the powder or dust.)
5. How can you achieve a better result for the area covered by one drop of the acid? (By taking the average radii produced by one, two, or three drops.)
6. What is the molecular weight of oleic acid? (282.) What is its density? (0.895 grams per cubic centimeter.)
7. Knowing the information about oleic acid from the previous question, how can you use the molecular diameter of oleic acid to calculate Avogadro's Number?

   (Divide grams per mole by grams per cubic centimeter to get volume of a mole of oleic acid. Then divide cubic centimeters per mole by cubic centimeters per molecule to get N, the number of molecules per mole, which is Avogadro's Number.)

   What assumption must you make? (You must assume some standard shape for the molecule of acid, such as cubical, spherical, rectangular, or some other shape.)

8. What is your calculated result for Avogadro's Number? (Student answer.) What is the generally accepted value? (Approximately 6×10^{23} molecules per mole.) How might your assumptions made in Question 7 affect your final result? (If you assume a cubical shape, you may get too small a result. Actually the

molecule of oleic acid is believed to be about ten times as long as it is wide, and when lying on the water is oriented vertically with the small end in contact with the water surface. Thus, a better assumption would be that the volume of a single molecule is approximately $h^3 \times 10^{-2}$ cubic centimeters.)

9. Tabulate the data obtained in this experiment, show your calculations and the final result.
10. Your experiment report should describe the problem you are attempting, a brief description of your procedure and materials used, tabulations of your data, and the conclusions reached in the experiment. It should be written clearly enough that an uninformed person could read your report, understand it, and if necessary repeat the experiment on the basis of your report alone.

SUMMARY

The lesson plan is a guide for action, not a rigid blueprint to be followed unswervingly. It should be flexible and modified when needed.

Much thought precedes the writing of a lesson plan. Questions of "What is the purpose of the lesson?" "What major generalizations are to be taught?" "How is the material best presented?" "What kinds of individuals are in the class?" are considered before planning the sequence on paper.

The format of the lesson plan should be functional and comfortable to the teacher. Individual teachers select the format most useful to them. It is important to have it as concise as possible within the limitations of effective teaching. During the actual teaching, the lesson plan should be unobtrusive but available for reference.

At least two kinds of long-range unit lesson plans exist. The teaching unit is planned with a time sequence in mind and usually contains provision for statements of objectives, outlines of content, methods, materials, and evaluation techniques. The resource unit does not usually concern itself with chronology but may be thought of as a reservoir upon which to draw for daily lesson planning. It may contain lists of aims, important knowledge objectives, lists of activities and projects, suitable demonstrations and experiments, references, films, bibliographies, sample tests, assignments, and other teaching aids.

Planning for teaching by an inquiry or discovery method usually requires a somewhat different approach than more traditional methods. The role of the teacher becomes one of guidance and direction, with greater responsibility for learning placed upon the student himself.

plans must provide more time, more questioning, greater variety of materials, and willingness on the part of the teacher to allow individual variations in progress by students.

Thorough lesson planning is a necessary facet of effective science teaching. Good teaching does not happen by accident. It is particularly important that a prospective teacher of science recognize the values and benefits to be derived from careful, inspired planning in the art of science teaching.

Further Investigation and Study

1. Select a specific short-range objective for a science class, such as "to develop skill in correct use of the microscope" or "to learn how to use the slide rule." Plan a lesson to achieve this objective, incorporating the features of a good lesson plan.
2. Using the lesson plan prepared in Exercise 1, or a similar one, teach your classmates in a hypothetical classroom situation. Invite them to play the role of a secondary science class, with appropriate questions and activities. Solicit their constructive criticisms and comments.
3. Write behavioral objectives for a unit you plan to teach. Consider cognitive, affective, and psychomotor objectives. A useful form for writing behavioral objectives is found in Chapter 5.
4. Read Mager, *Preparing Instructional Objectives*, Fearon Publishers, 1962, and Kibler, Barker and Miles, *Behavioral Objectives and Instruction*, Allyn and Bacon Co., 1970.
5. Prepare a short talk for your fellow students on the pros and cons of the use of behavioral objectives.

Evaluation has five functions:

It helps the learner realize how he should change or develop his behavior (feedback to learner).

It helps the learner attain satisfaction when he is doing as he should (reinforcement).

It provides a basis for subsequent decisions about the learner: what courses he is ready for, what remedial treatment he needs, what job or college to recommend him to.

It helps the teacher judge how adequate his teaching methods are (feedback to teacher).

*It provides information for administrative judgments.**

13

Evaluation: Evaluating the Total Person's Behavior

Probably nothing is so well known and so little understood by teachers as evaluation. Evaluation involves the total assessing of a student's learning by the instructor. It includes evaluating understanding of the processes of science, subject-matter competence, multiple talents, scientific attitudes, laboratory skills, and ability and willingness to work. Not only the progress of the students toward the objectives of the course and school but also the effectiveness of the instructor are considered. Good evaluation indicates the strengths and weaknesses of instruction. Once a teacher has made a thorough assessment, he has an indication of how to improve his teaching. Evaluation acts as the feedback in the experimental process of teaching. A teacher must be experimental if he is to progress and try to become more skilled. He must be willing to try new methods and new techniques and in so doing evolves toward teaching mastery. Science teachers above all should be experimental, not only in the laboratory but in their daily approaches to teaching; however, an experimental approach assumes collection of data to verify

*Lee J. Cronbach, *Educational Psychology* (New York: Harcourt Brace Jovanovich, 1963), p. 539.

the success of the method used. The data in this case must come from the evaluating techniques. The better the evaluating instruments the greater the information available to the teacher for improving his course and instruction.

Listed below are general evaluational techniques used by teachers. It must be emphasized that testing is only a part of evaluation and probably receives too much attention at the expense of other methods:

Tests

1. *Standardized tests.* There are several standardized tests in science. All of the new curriculum studies have produced standardized tests or are in the process of doing so. These tests include (a) achievement tests in specific subject areas, (b) aptitude tests, (c) understanding-of-science or critical-thinking tests, (d) tests to determine creative ability.
2. *Essay tests.* These should require a sufficient sample of the subject matter. A teacher should refine his essay questions by studying student performance on past tests.
3. *Problem tests.* A problem or a situation is presented, and the students are asked to suggest plausible answers. This type usually involves experimental procedure or judging information from an experiment.
4. *Simple recall tests.* Avoid these.
5. *Multiple-choice tests.*
6. *Matching tests.* Avoid these.
7. *Self-tests.*
8. *Completion tests.*

Nontest evaluations

1. Behavorial records. These are based on laboratory or field work. The teacher prepares a checklist of how the individual functions in these situations.
2. Analysis of creative work. This may involve the production of some piece of apparatus, art work, or a science project.
3. Student self-evaluation of performance in the course or unit.
4. Interpretation of written and oral presentations.

Because of the complexity of evaluation it is strongly urged that science teachers get some advanced special training, particularly in testing and measurement. Some states now require this before a teacher can be certified. In the sections to follow only two aspects of evaluation are considered because they are of greatest importance to science teachers. Those selected are (a) evaluation of laboratory work and (b) testing.

Other than by paper and pencil tests, how would you evaluate what these students are learning?

Courtesy of Bob Waters, University of Northern Colorado

EVALUATING LABORATORY WORK

Laboratory work is an important part of all new science programs; however, evaluating lab work presents a difficult task. Science teachers generally require students to hand in reports on their laboratory work. This has value as long as the laboratory manuals do not require cookbook answers, simply filling in blank spaces. All the new curriculum-development laboratory exercises stress guiding questions rather than those requiring fill-in answers; however, the techniques of reporting in the new curriculum laboratory books is left to the discretion of the individual instructor.

All students should have some experience in reporting laboratory work as scientists report theirs in journals. The criticism of the cookbook approach is that it is unrealistic. Scientists do not have an outline of questions to answer or simple small spaces to fill in when they actually do research.

Scientific research, however, is reported in a definite manner as indicated below:

REPORTING EXPERIMENTAL RESULTS
1. Statement of the problem
2. Hypotheses
3. Experimental design and procedure
4. Data
5. Conclusions

It is suggested that students sometimes be encouraged to follow this format in reporting the results from their experiments. This approach helps to make the student reason and think about what he has done.

A science teacher who has five classes (150 students) a day cannot, because of sheer numbers, correct all laboratory work reported in this form. Many schools enlist student assistants to check laboratory work for the teacher. The science teacher occasionally then only spot-checks the reports. However, the first written reports should be gone over in detail so that students start with a better understanding of what is required and know that their work may be critically evaluated. Teachers who have no assistants usually spot-check reports and spend more time in discussion covering the laboratory work.

Practical Laboratory Tests

Practical and written examinations covering only laboratory work are used as a means of evaluation. Practical laboratory work involving the testing of materials, determining unknowns, recognizing and classifying organisms, and outlining experimental procedures is valuable. The problem with practical laboratory examinations is that they take a considerable amount of time to set up. Student laboratory assistants or one or two *A* students can be of considerable help in setting up the examination before or after school.

BSCS has suggested a format to be used in setting up and giving a "practical," a portion of which is shown below:[1]

Set-up:

Problem 1. *Measuring the rate of photosynthesis*
On the table are three beakers filled with water. In each is an inverted funnel containing several sprigs of fresh elodea. On the funnels are cali-

[1]P. Tamir and S. Glassman, "Laboratory Test for BSCS Students" *BSCS Newsletter #42* (February 1971): 9 and 10.

brated test tubes. The first set-up is in the direct light provided by a 100-watt lamp. The second set-up is about one meter distance from the lamp. The third set-up is completely concealed under a heavy paper cylinder. There are also two liter bottles containing a solution $NaHCO_3$. (If the set-ups are arranged about one hour before the students arrive, there is a clearly discernible difference in gas level in the test tubes.)

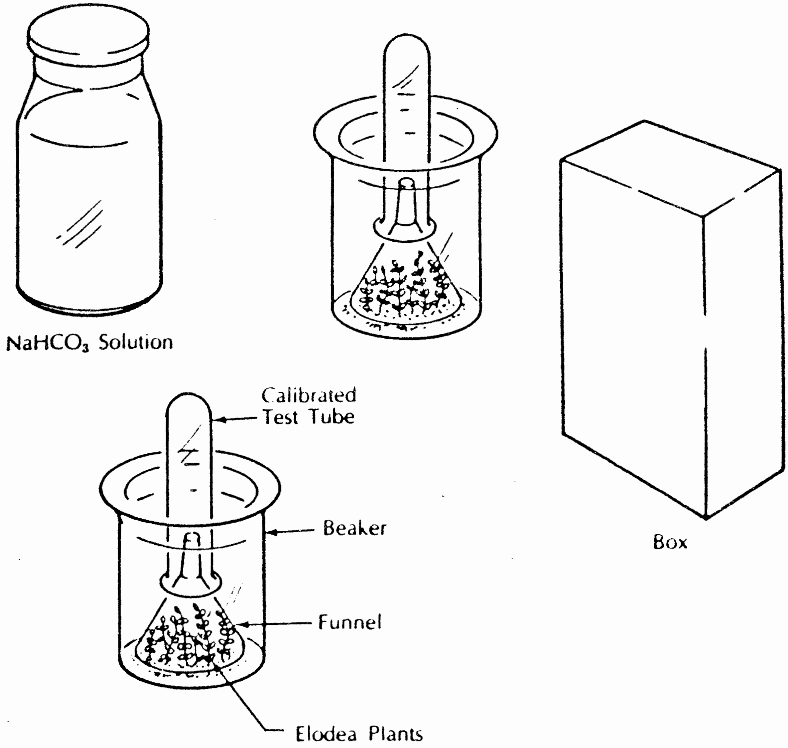

Figure 31

Problem 1.

1. Examine the rate of photosynthesis of the three set-ups in front of you. Write the results.
2. What is the control in this experiment?
3. How would you explain the results? Indicate the major processes occurring in each of the set-ups.
4. What is the gas that collects in each of the test tubes? How can you test this?
5. Why did we use a water plant in this experiment? (elodea)
6. You have more elodea twigs. Design an experiment whereby you will be able to measure the rate of photosynthesis in a different way. Before you begin, call the examiner and show him your plan. Perform the experiment and write the results.

7. *How would you speed up the rate of photosynthesis in the experiment that you designed? (Hint: look at the equipment and materials on the table.)*
8. Determine quantitatively if and to what extent you succeeded in speeding up the rate of photosynthesis. Write your results. Is there any control in this experiment?
9. What are your conclusions from all the experiments that you did?
10. Write down a hypothesis based on the results of the experiments you performed.
11. Describe, in short, how you can test your hypothesis experimentally.

TESTING

Look over a segment of the following test. Consider what is good and bad about this test.

Select from Column *B* the answer which best fits Column *A*.

Column A	*Column B*
1. Roundworms	a. Mammalia
2. Flatworms	b. Echinodermata
3. Snakes	c. Aves
4. Birds	d. Platyhelminthes
5. Paramecium	e. Nemathelminthes
6. Dogs	f. Protista
7. Starfish	g. Porifera
8. Sponges	h. Reptilia
9. Whales	i. Protozoa
10. Fishes	j. Rotifera
11. Diseases and pathogens able to pass directly from one host to another within a population	k. Anopheles Mosquito l. Mosquito (Aedes) m. Contagious
12. The parasite which is the causative organism of a disease	n. Aerobic o. Anaerobic
13. The insects which, along with man, are alternate hosts for malaria	p. Pathogen q. Slime mold
14. The vector insect of yellow fever	r. Louis Pasteur
15. Oxygen-requiring bacteria	s. Charles Darwin
16. A visible living protist which glides along using an amoeboid movement	t. Animalcule u. Pasteur v. Protista
17. The scientist who definitely killed the idea that microbes might arise spontaneously from dead materials	w. Euglena x. Rickettseae y. Anticoagulent z. Leeuwenhoek

18. Discovered the world of microscopic life in the 1670s.
19. The name which represents the whole group of subvisible creatures
20. Means *little animals*
21. The man responsible for the great classification system in 1750s

aa. Linnaeus
bb. Salivary glands
cc. Denitrification
dd. Nitrogen cycle
ee. Vector
ff. Flagellate
gg. Noctituca
hh. Rickettsibe

Refer to the test again. What is wrong with the format of the test? Where will the students place the answers? What of the number of answers to match the questions? Does it test for scientific principles, understanding of science as a process, or simply recall of information?

Tests Should Evaluate Your Objectives

Just as Bloom has pointed out that there are levels of objectives so are there levels of testing. The above examination does not test for the important objectives of science. A teacher trying to evaluate the quality of his instruction from this test has little indication of how well he is teaching. The test clearly indicates that the teacher, as he wrote the test, did not consider his objectives or the scientific principles he wished to teach. The first rule of test construction is *to use your objectives* and scientific principles as a guide in making a test; otherwise, there is little use in having one. It is worth repeating that students tend to learn the way they are tested. Are the things the above test emphasizes really the important goals of the course?

When tests are given they should evaluate how well students attained the behavioral objectives of the course, whether the objectives were student or teacher defined. It is relatively easy to write behavioral objectives, but to evaluate their achievement is often difficult.

Most beginning teachers, at first, tend to want to write only essay types of questions. It is easier to do this than write multiple-choice questions for the same objectives. However, essay questions have limitations as indicated below:

LIMITATION OF ESSAY QUESTIONS

1. They limit the sample. Since few questions can be answered in the time allotted, only a small sample of the total learning is made.
2. They require extensive correction time. Remember you shall probably have 100 or more students a day in your classes. If each student writes 4 questions requiring 15 seconds of

correction time per question, on an average you will need:
100 students × 4 questions × 15 seconds per question = 6000 sec.

$$\frac{6000 \text{ seconds}}{60 \text{ sec/min}} = \frac{100 \text{ minutes}}{60 \text{ min/hr}} = 1 \text{ hr., } 40 \text{ min.}$$

This is a considerable amount of time.

Although learning to write multiple-choice questions initially requires considerable time, by doing this, an instructor will be ahead in the long run because they require far less correction time. Furthermore, they may be corrected by students in class.

Writing Test Questions for all Levels of Bloom's Taxonomy

Recall that Bloom stipulated there were five cognitive levels of objectives. There should, therefore, be questions to evaluate each of these levels. Note in some of the sections below the behavioral objective has been stated and then the question evaluating it. If you have written excellent behavioral objectives and you use them as a guide for constructing your tests, they probably will be better examinations than those prepared by many experienced teachers who do not follow their objectives in test construction.

Levels of Testing

1. *RECALL—KNOWLEDGE LEVEL*

The matching test above mainly stresses recall. Simple recall is the lowest level of learning. It requires only memorization of information—and information is not knowledge in the broad sense. Animals can memorize. To teach mainly for recall is the lowest level of instruction, but teachers have often devoted too much time to this level because recall questions are simple to write. Other levels must become a part of all tests. No more than 20 percent of any test should consist of simple recall questions.

2. *COMPREHENSION*

To comprehend is to understand. Students may know something, e.g., osmosis, momentum, density, but not understand it. Comprehension types of questions ask students to:

a. Interpret a statement.
b. Translate — describe a process or idea in their own words.
c. Extrapolate — go beyond the data.
d. Interpolate — supply intermediate information.

You are probably already fairly familiar with the knowledge and comprehension levels of Bloom's taxonomy. For this reason greater attention will be devoted to its higher levels. Shown below, (beginning with point 3. *Application*) is a portion of the *Summary Description of Grade Nine Science Objectives and Test Items* (Revised Edition) prepared at the direction of the High School Entrance Examinations Board, Department of Education, Edmonton, Alberta, March 1965. The Board has endeavored to test for all levels of the taxonomy. Their booklet is provided to the Alberta teachers so they see how their junior high school students will be evaluated by the Department of Education. Note in the following sections a brief description of each level is presented first. This is then followed by a list of objectives and essay and multiple-choice test items to evaluate them.

(3) APPLICATION

Application can best be described by comparing it with comprehension. A problem in the comprehension category requires the student to know an abstraction well enough that he can correctly demonstrate its use when he is specifically asked to do so. Application, on the other hand, requires a step beyond this. Given a problem new to the student, he will apply the appropriate abstraction without having to be prompted as to which abstraction is correct or without having to be shown how to use it in that situation. In comprehension the student shows that he *can use* the abstraction when its use is specified. In application the student shows that he *will use* the abstraction correctly given an appropriate situation in which no mode of solution is specified.

It is not necessary always to require a complete solution. Sometimes a partial solution or selection of the correct abstraction alone is requested. In all cases, however, the task should use material the student has not had contact with, or take a new slant on common material or use a fictional situation. If the material is familiar, comprehension or recall is required, not application.

Some Objectives

1. Applies scientific concepts and principles used in class to the phenomena discussed in a paper.
2. Predicts the probable effect of a change in a factor on a chemical solution previously at equilibrium.
3. Applies scientific principles, postulates and other abstractions to new situations.
4. Finds solutions to problems in making home repairs employing experimental procedures from science.

Some Items

1. What effect would an increase in pressure in the boiler of a steam engine have upon the performance of the steam engine?
2. A baseball can be made to curve. How can this be explained?
3. Would the air in a closed room be heated or cooled by the operation of an electric refrigerator in the room with the refrigerator door open?

   *A. heated, because the heat given off by the motor and the compressed gas would exceed the heat absorbed.
   B. cooled, because the refrigerator is a cooling device.
   C. cooled, because compressed gases expand in the refrigerator.

D. cooled, because liquids absorb heat when they evaporate.
E. neither heated nor cooled.

Items 4 and 5 are based upon the following situation.

The boiling and freezing points of water were determined and marked on the glass of a new, and as yet "blank" thermometer. If these two points are 9 inches apart, how far apart would the degree markings be if it were desired to make:

4. A Centigrade therometer?
   A. 9/180 inch
   *B. 0.09 inch
   C. 0.9 inch
   D. 9/16 inch
   E. 9/32 inch
5. A Fahrenheit thermometer?
   *A. 0.05 inch
   B. 0.5 inch
   C. 0.09 inch
   D. 9/100 inch
   E. 9/32 inch
6. An automobile weighing 3,300 lbs. goes up a hill 160 ft. high in 20 secs. The output of the motor in horsepower must be:
   A. 8
   *B. 48
   C. 412.5
   D. 10,560,000

Note: Item 6 should be classed as "Comprehension" if it is parallel to, or similar to items taken in class. In Items 4 & 5 the situation is probably novel—it has a new twist. Item 6 might be made novel to most students, for example, by including the length of the hill.

4. *ANALYSIS*

Analysis is related to both comprehension and evaluation. In comprehension the emphasis is on the grasp of the meaning and intent of the material. Analysis emphasizes the breakdown of the material into its constituent parts and detection of the relationships of the parts and of the way they are organized. It is also sometimes directed at the techniques and devices used to convey the meaning or to establish the conclusion of the communication. Comprehension deals with the content of the material alone, analysis with both content and form. On the other hand, evaluation involves more than analysis or even critical analysis in that, when one evaluates, in addition to analyzing a judgment is made in terms of some criteria as to its adequacy.

Some Objectives

1. Recognizes unstated assumptions.
2. Distinguishes facts from hypotheses.

3. Distinguishes conclusions from statements which support it.
4. Checks consistency of hypotheses with given information and assumptions.
5. Distinguishes cause and effect relationships from other sequential relationships.
6. Detects the purpose, point of view, attitude, or general conception of the author.

Some Items

1. "Light is produced indirectly in the fluorescent lamp." What would be another way of expressing the conclusion implied in the above statement?
2. 1 liter = .88 qt. Are there more quarts than liters in a container whose capacity is 1000 cc?

Item 3 contains a pair of statements which are either in agreement with each other or not in agreement, and either of the statements may be true or false. Study the pair of statements and choose:

A. if statements I and II are in agreement and both false.
B. if statements I and II are in agreement and both true.
C. if statements I and II are not in agreement; I true, II false.
D. if statements I and II are not in agreement; I false, II true.

3. I. At absolute zero the molecules of a substance do not move with respect to each other.
   II. No heat energy is possessed by a substance at absolute zero.
   [Key: (B) *Note*: This pair of statements is only illustrative as other pairs of statements could be added to make use of the same alternatives.]

The following paragraphs concern the action of a geyser. Read the passage carefully before answering Items 4 - 8 inclusive.

A geyser is a hot spring that erupts at intervals. It is made up of a more or less crooked or constricted, tubular fissure that extends into the earth and is filled with water. A source of heat near the bottom of the fissure heats the water.

After an eruption the tube fills with water from an underground source. The water throughout most of the length of the tube, and especially in the lower part, becomes heated to a point above the normal boiling temperature (212°F.) of water but does not become quite hot enough to turn to steam. However, sooner or later, some of the water in the lower part of the tube at the source of heat reaches the boiling point and turns to steam. The steam raises the whole column of water above it and causes some water to overflow from the geyser pool at the surface. This overflow acts as a trigger, permitting the whole column of water in the tube to flash into steam which blows from the fissure in an eruption.

For each of Items 4 - 6 choose:

A. if the statement is true and pertains directly to the action of the geyser.
B. if the statement is true but is not directly concerned with the action of the geyser.
C. if the statement is false.

4. If the tube were not crooked and constricted the water throughout the tube would come to nearly the same temperature by unrestricted convectional circulation, the water would boil, and a boiling spring rather than a geyser would result.
5. The boiling point of water in the bottom of the tube is lower than it is at the top.
6. The water in the tube does not turn to steam although it is above the normal boiling point because of the pressure of the overlying water.

[Keyed answers are: 4 (A), 5 (C), 6 (A).]

7. Air pressure on a fine day is usually higher than on a stormy day. Thus, the geyser will erupt more often during stormy weather. This statement can best be evaluated as:
   A. a wild guess.
   *B. true, because it can be predicted from known principles.
   C. false, because it cannot be predicted from known principles.
   D. true, because it is based on statements in the above passage.
   E. false, because it contradicts the statements in the above passage.
8. An investigation of which one of the following hypotheses concerning the boiling point of water is most suggested by the observation of a geyser?
   A. the boiling point of water decreases with increasing altitudes.
   B. the boiling point of water is that point when the vapor pressure equals the atmospheric pressure.
   *C. the boiling point of water in a pressure cooker is above 212°F.
   D. the boiling point of water in a hot water heating system is above 212°F.

(*Note:* Item 4 is classified as Analysis, 5 as Knowledge of Specifics, 6 as Comprehension, 7 as Evaluation, and 8 as Synthesis.)

5. SYNTHESIS

Synthesis emphasizes the putting together of elements and parts in such a way as to constitute a pattern or structure not clearly there before. Generally this involves a recombination of parts of previous experience with new material reconstructed into a new and more or less well-integrated whole. This is the category in the cognitive domain which may not always be free creative expression since generally the student is expected to work within the limits set by particular problems, materials, or some theoretical or methodological framework.

Some Objectives

1. Describes an original experiment conducted by a student.
2. Proposes ways of testing an hypothesis.
3. Integrates the results of an investigation into an effective plan or solution to solve a problem.
4. Develops schemes for classifying chemicals.
5. Formulates hypotheses to explain adequately a wide range of seemingly interrelated phenomena and be internally consistent.
6. Makes deductions from basic theories.

Some Items[2]

1. How could you construct an oil barometer from oil which floats on water?
2. Given: 1. Work = fd.
   2. Power is work per unit of time.
   3. 33,000 ft. lb. per min. = 1 H.P.

   Develop the formula for Horsepower H.P. =
3. You suspect that a certain soluble compound contains hydrogen. Which of the following would be a way of checking your suspicion?
   A. prepare a solution of the compound and subject it to electrolysis, using Hoffman's apparatus.
   B. place a sample of the compound in a Bunsen flame and determine if any water vapor is produced.
   C. heat the compound to incandescence and analyze the light produced with a pyrometer.
   *D. vaporize some of the material in a flame and use a spectroscope to analyze the light produced.
   E. pass some light through a solution of the compound and analyze the spectrum produced with a spectroscope.
4. See also Item 8 under Analysis.

6. *EVALUATION*

Evaluation includes the process of making judgments concerning the extent to which ideas, solutions, methods, and materials satisfy criteria. It involves the use of criteria as well as standards for appraising the extent to which particulars are accurate, effective, economical or satisfying. The judgments may be either quantitative or qualitative and the criteria may be either those determined by the student or those which are given to him.

Some Objectives

1. Detects the logical fallacies in arguments.
2. Discerns the inconsistencies and/or logical inaccuracies in data.

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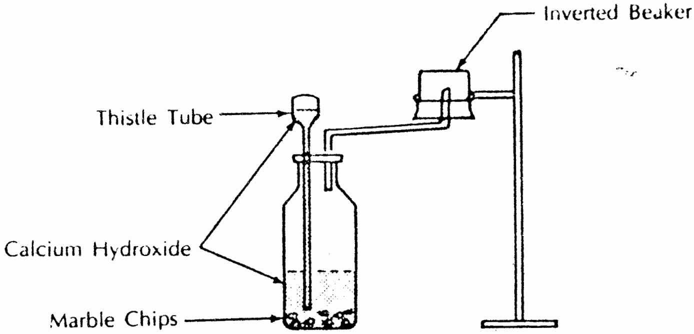
[2] It is extremely difficult to write objective items to measure synthesis and evaluation. Bloom provides several examples in science. The Physical Science Study Committee Tests published by Educational Testing Service also have examples.

3. Identifies the procedural errors in an experiment and evaluates their effect on the results.
4. Compares the effectiveness of a method used to solve a problem with the best possible method available.
5. Identifies additional evidence or experimentation that is necessary to fully justify the conclusions reached.



Some Items

The above apparatus was set up to prepare carbon dioxide. The contents of the inverted beaker were tested with lime water which did not turn milky. It was concluded that the calcium hydroxide solution was not strong enough.

1. What logical inconsistencies are there in the report of the experiment?
2. Identify the procedural errors in the experiment and evaluate their effect on the results.
3. A recent popular article stated that, if a space craft were being rocketed away from the surface of the earth fast enough, its speed would offset the pull of gravity and a man in the rocket would feel weightless. This statement should be evaluated as being:
   A. accurate since two forces are involved in the described situation and two forces can offset one another.
   B. accurate since the weight of an object decreases rapidly as the distance from the center of the earth decreases.
   *C. inaccurate since the floor of the man's compartment will be pushing up on the man as the rocket rises, and this push will give a feeling of increased rather than decreased weight.
   D. inaccurate since no object within the gravitational field of the earth can be weightless and so cannot seem weightless
   E. inaccurate since the chance that the force on the man due to the rocket moving up and the force of gravity pulling the man down will be equal is extremely minute.
4. See also Item 7 under Analysis.

The Edmonton Department of Education has used a grid to insure that all levels of the taxonomy are evaluated. Teacher-made tests may also be analyzed by using this grid. The following chart indicates how you may use it to determine the sophistication of your testing procedures.

BLUEPRINT OF GRADE NINE SCIENCE EXAMINATION, 1965[3]

OBJECTIVES	Topic or Content Area									Emphasis %
	Matter and Energy Force, Work & Power	Mechanics		Chemical Reactions	Heat	Light	Transportation	Measurement*	Science as Inquiry*	
		Machines	Fluids							
1. KNOWLEDGE										40
2. COMPREHENSION										30
3. APPLICATION										20
4, 5, and 6 — ANALYSIS, SYNTHESIS AND EVALUATION										10
Emphasis %	5	15	5	15	15	15	10	5	15	100

*Note: The topics "Measurement" and "Science as Inquiry" cut across Content Areas. The latter category will be used for items that involve more than one content area or that involve inquiry as, for example, Items 6 to 10 under Analysis.

Affective Domain

Although the above chart is designed to analyze the cognitive domain only, it can be easily modified to include the affective domain by adding a fifth category on the left-hand side of the chart entitled: Affective Domain. Performing several analyses of tests using this grid helps to insure your growth in making better tests evaluating for the higher levels of learning. Refer back to Chapter 3, Further Investigation and Study section, to see how interest was evaluated on Piaget's theory.

Teachers who do not evaluate all their objectives or classify their test questions in some way similar to the grid above tend to evaluate for the lowest levels of Bloom's Taxonomy. Scannel and Stillwagen, for example, in sampling 46 chemistry teachers' tests from four-year high schools, found that the major emphasis was on knowledge. The application, analysis, and synthesis levels were virtually neglected.[4]

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[3]From *Summary Description of Grade Nine Science Objectives and Test Items*, Revised Edition, Prepared at the direction of The High School Entrance Examinations Board, Department of Education, Edmonton, Alberta, March 1965.

[4]Dale P. Scannel and Walter R. Stillwagen, "Teaching and Testing for Degrees of Understanding," *California Journal of Instructional Improvement*, (March 1960): 88-94.

EVALUATE SCIENCE PROCESSES

One of the major goals of science teaching is to develop an understanding of the processes of science. This can be evaluated in three ways:

1. The student evaluates himself.
2. The instructor checks on an observational form how well a student performs certain processes.
3. An instructor tests for the attainment of the processes.

Shown below is a form that can be used as indicated in numbers 1 and 2 above.

OBSERVATIONAL OR SELF-EVALUATIONAL INVENTORY OF STUDENT BEHAVIOR

	Seldom	Sometimes	Often
A. *Creative Processes*			
1. Formulates Problems			
2. Hypothesizes			
3. Designs Experiments			
4. Makes Inferences			
B. *Other Inquiry Processes*			
1. Records accurate observations			
2. Makes comparisons			
3. Quantifies			
4. Classifies			
5. Collects data			
6. Organizes data			
7. Interprets data			
8. Graphs when needed			
9. Makes operational definitions			
10. Identifies assumptions			
C. *Scientific Attitudes*			
1. Demonstrates *objective* attitude by presenting evidence *for* and *against* an idea (Eg., drugs, alcohol, or smoking)			
2. Suspends judgment until he has investigated objectively the subject or states he has insufficient information to make any definite statements			
3. Indicates curiosity about observations by asking questions and making investigations			
4. Indicates in discussion he knows the difference between hypotheses, solutions, facts, inferences by making such statements as: My hypothesis is...The solution is... The facts are...One inference is...			
5. Changes opinions when confronted with evidence			

	Seldom	Sometimes	Often
6. States in using statistical data where warranted that although there is a correlation this does not necessarily mean a cause and effect relationship			
7. States cause and effect relationships			
8. Evaluates his and others' procedures and information in experimentation			

The list above should serve as a guide to help you construct test questions to assess how well students are learning the processes and attitudes of science. *All science tests should have some questions to evaluate these.* Examples of how these questions can be written are shown below.

1. RECOGNIZING A PROBLEM

a. A student goes to Mexico for three days of vacation. After he returns to the United States he becomes nauseated. What would a scientist do when confronted with this situation—and why?

b. A student set up a science demonstration consisting of a coffee can, a spark plug stuck in the top of the can, and a spoonful of gasoline. The gasoline was placed in the can and the plastic lid attached with the spark plug gap end hanging down inside the can. The student connected the spark plug to some dry-cell batteries. Nothing happened. The student didn't know what to do. What do you think the demonstration was supposed to show? What would you do in such a situation and why?

2. LEARNING TO MAKE HYPOTHESES

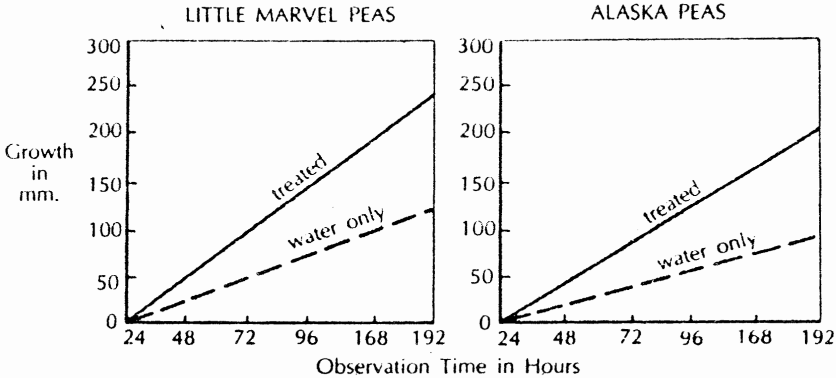
The following questions require students to make hypotheses:

1. High in the mountains a dam suddenly breaks. What possible hypothesis could you give for such an occurrence?
2. A candle is placed in a tray. Water is added to the tray so that it is two inches deep. The candle is lit. The candle is covered with a jar. What will happen and why? Which of the following hypotheses do you think to be valid?
   a. The water level will remain the same in the jar.
   b. The water level will be lower in the jar than in the tray because the heat of the candle will cause water to evaporate.
   c. The water level will rise because all the oxygen will be burned up, causing less gas pressure in the jar.
   d. The water level will be lower because when the candle burns it produces carbon dioxide in the jar, which will cause greater gas pressure, forcing water out of the jar.
   e. The water level will rise because the candle gives off heat. This causes expansion of gases around the candle. When the

jar is placed over the candle, the candle goes out, the air cools, and has less pressure than room-temperature air. The water level then rises.

3. INTERPRETATION OF DATA AND MAKING VALID CONCLUSIONS

I. In a controlled experiment involving the effect of Gibberellic acid on the growth of Alaska peas and Little Marvel peas, from the period immediately after germination to 8 days of growth, the following data were observed:



From the data in the graph, which of the following conclusions are (a) reasonably certain, (b) supported by experimental evidence, (c) not confirmed by experimental data? Mark your answers a, b, or c.

____ 1. Gibberellic acid is a strong growth-stimulating factor.
____ 2. Gibberellic acid is the only auxin that acts on pea plants specifically.
____ 3. Gibberellic acid has a marked effect on dwarf-type pea plants.
____ 4. Gibberellic acid acts specifically on the stems but has no effect on growth of roots.
____ 5. The function of using plants treated with water was to justify the factor that growth was not due entirely to water.
____ 6. The effect of Gibberellic acid is the same on other dwarf plants as it is on dwarf peas.
____ 7. Had the experiment been continued for longer than seven days the Gibberellic acid would have had no effect.
8. Straight-line growth is the only effect that Gibberellic acid has on peas.

II. During controlled experiments, the effects of various concentrations of auxin indole acetic acid on the growth of oat coleoptiles from which the tips have been removed were measured. The coleoptiles selected from seedlings germinated in darkness were placed in sugar solution with indole acetic acid as indicated in the table below. Growth effects were observed at the end of 24 hours.

COLEOP-TILE	CONCENTRATION MG/L. AV. CHANGE IN LENGTH					
Initial Length	Sugar 290	IAA .01	IAA 0.1	IAA 1.0	IAA 10.	Unknown IAA Sol.
2.0	2.8	3.4	5.1	7.0	2.1	6.3
2.1	2.6	3.0	4.9	6.8	2.1	6.2
2.2	3.0	3.3	5.2	7.0	2.3	6.0
2.2	2.8	3.3	5.1	7.2	2.3	6.1
2.0	2.4	2.8	5.0	7.1	2.1	6.0

Does the analysis of the experimental data seem to indicate that the following are true or false?

_____ 9. From the data in the table it is indicated that the optimum concentration of IAA is between 0.1 mg and 1 mg/liter.

_____ 10. Increasing concentration from zero produces the same proportional increase in growth rate.

_____ 11. Concentration of IAA influences cell division but has little effect on cell growth and elongation.

_____ 12. Removal of the coleoptile tip removes the source of plant auxin.

_____ 13. Coleoptiles are selected from seeds germinated in darkness because light greatly increases the production of plant auxin.

_____ 14. Above a certain concentration of IAA growth is actually inhibited.

_____ 15. Based on the growth rate of the various concentrations, the unknown solution is about 0.05 mg/l.

4. *DEVISING EXPERIMENTS*

a. How would you find out whether soda pop is harmful to your teeth?

b. How would you determine which metal is the best conductor of electricity?

c. You suspect that a special plastic material used to coat floors might cause lung cancer. How would you go about proving this?

d. You suspect a certain chemical is a stimulant. How would you find out?
e. You believe you have a mutant mold strain that has lost the enzyme capable of digesting certain carbohydrates. How would you prove this?

QUANTITATIVE TERMS

All sciences use mathematics. The use of mathematics insures more accurate communication and brings exactness to science where vagueness once flourished. When we describe phenomena, we may do so by use of dichotomous or metrical terms. A dichotomous explanation is of the "either-or" type, such as: it is tall (or short), small (or large), heavy (or light). Science strives to escape from explanation of this type because it contributes to ambiguity; what may be tall to one person may be small to another. Scientific explanations are usually given in metrical terms. Instead of saying a person is tall, a scientist says he is 6 feet, 4 inches tall. Instead of stating, "Place some glucose in water" he is more likely to say, "Place 10 grams of glucose in 100 cc of water." The use of metrical terms insures exactness.

Exactness in science is important not only for insuring better communication but in replicating research as well. It is the nature of the scientific enterprise to have one scientist check the results of another. This would be impossible without the use of exact metrical terms. Compare the following and this becomes obvious.

A nonmetrical explanation: "A small amount of penicillin was injected into a human organism suffering from a bacterial infection. The infection was cured in a short time."

A metrical explanation: "Sixty subjects and ten control patients infected with streptococcus were administered 500,000 units of penicillin. On the third day, forty of the patients no longer evidenced the infection in the nasalpharyngeal passages."

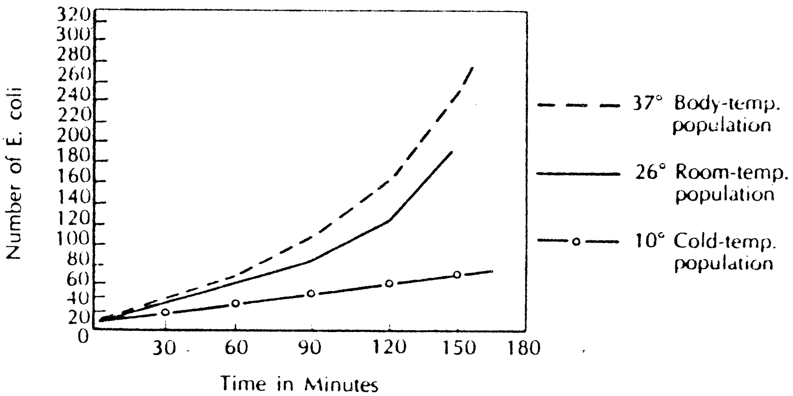
The importance of metrical terms can be easily pointed out to a class by holding up an eraser and having them describe it in complete detail so that it could be produced by some African tribesman who had never seen one. Students will often write down a description without giving exact dimensions. An instructor can then discuss the necessity of giving the dimensions, thereby emphasizing the place of math in science. There are other uses of mathematics in science aside from those discussed here, but the important point is that mathematics become a part of each examination and students gain insight into its association with science.

Using Graphs in Testing

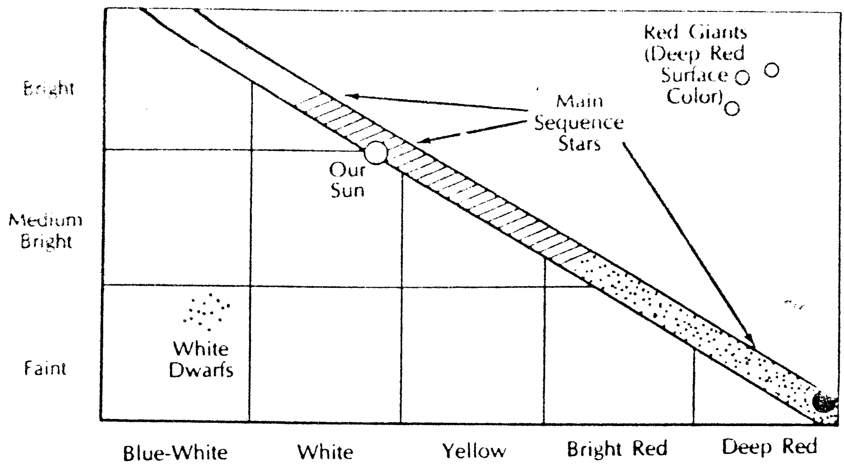
One quantitative tool used to a considerable extent in science is graphing. Graphing has the following advantages: (1) It conveys a tremendous amount of information in a small space. Try to describe verbally all the information depicted by a curved line on a graph, and this point immediately becomes apparent. (2) It helps the viewer to see quickly relationships which are not so apparent when one looks at a set of numbers. (3) A pictorial representation of data is retained more easily by students than are other forms of data. Below are examples of graphing exercises used in secondary science:

GRAPH INTERPRETATION

I. This graph represents data collected on *E. coli* bacteria in the laboratory. *E. coli* is found internally in a symbiotic relationship with man.



1. From the data given, what are your conclusions about the effect of temperature on *E. coli* population?
2. At 37°C approximately how long does it take for *E. coli* to double its population? at 10°C?
3. Why do you think *E. coli* is successful in its relationship with man?
4. What would be the approximate population of *E. coli* in 4 hours at 37°C? at 26°C?
5. Each population is in 100 ml. of nutrient. What could you predict about the eventual curve of bacteria populations at 37°C? at 10°C?
6. Which of the three populations will reach its maximum growth development first? Why?



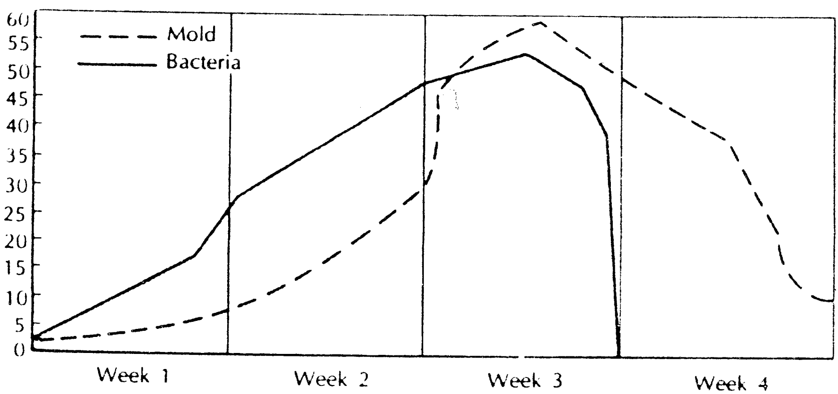
___1. The graph above indicates that which of the following is not true?

A. The sun is an exceptional star.
B. The sun is a medium bright star.
C. The sun is between yellow and white in color.
D. The sun will some day become a red giant star.

___2. Which of the following is true of the information found in the graph?

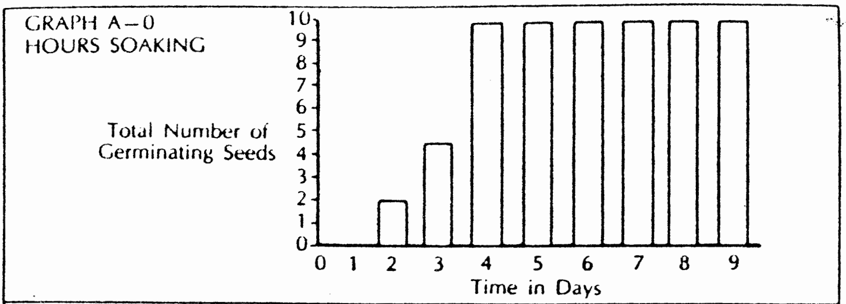
A. Red giant stars are faint.
B. The sun is a main sequence star.
C. White dwarf stars are brighter than red giants.
D. Deep red stars and red giant stars have the same weight.

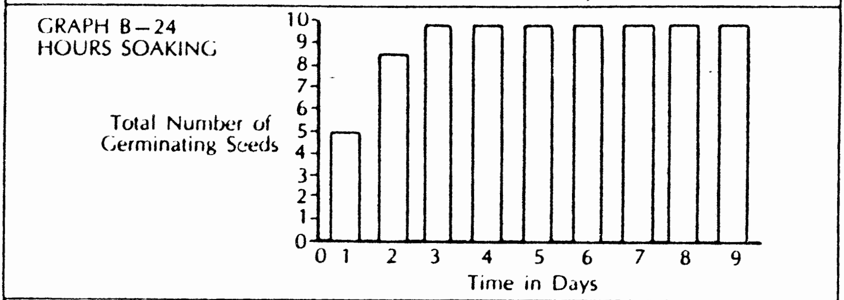
II. A flask of sterile beef broth was inoculated with a single species of bacteria. The flask was not sealed, and thus mold spores were able to enter. The growth patterns for the bacteria and mold are shown in the graph below.

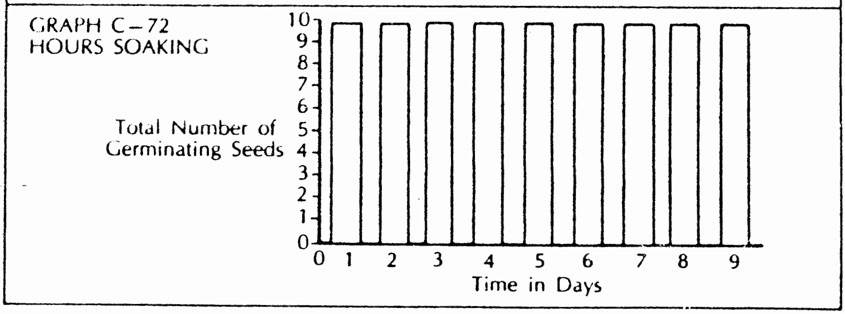


From the graph above answer the following questions:

1. Why do you think the bacteria flourished at first and then all died by the end of the third week?
2. Why do you think the mold population decreased so rapidly during the fourth week?
3. Notice the shape of the growth curve for the mold during the first two and a half weeks. What important concept of growth rate does this illustrate?







III. Answer the following questions in relation to conclusions that can be drawn from the graph. Before being tested for germination, corn seeds represented in Graph *A* have been soaked 0 hours; in Graph *B*, 24 hours; and in Graph *C*, 72 hours.

1. Farmer Brown wants to plant corn seeds and get them up as soon as possible. From the graphs, how long would you advise him to soak

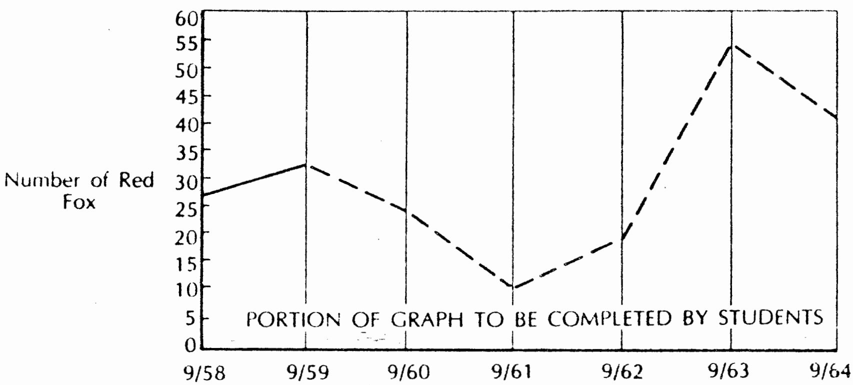
the seeds prior to planting? (a) 0 hours, (b) 24 hours, (c) 72 hours

2. Which of the graphs shows maximum germination after three days? (a) Graph A, (b) Graph B, (c) Graph C
3. How many days does it take for 50 percent germination of seeds soaked for 24 hours? (a) 1 day, (b) 2 days, (c) 4 days, (d) 10 days
4. Moisture applied to seeds for 24 hours before planting has a greater effect on seed germination than soaking them (a) 0 hours, (b) 36 hours, (c) 72 hours, (d) 100 hours
5. From the graphs above, which group of seeds would be considered the control? (a) that in Graph A, (b) that in Graph B, (c) that in Graph C

COMPLETION OF A GRAPH

Another way to determine students' understanding of graphing is to have them complete a graph. The graph test below can be used in a regular assignment or done as homework:

The following graph applies to the red-fox population on an island which is 10 miles long and 20 miles wide. It is located in the center of a very large lake in central Canada. This island supports several species of animals; however, detailed population studies have been conducted only on the fox population. These population studies began in 1958 and continued for six full years.



During part of the year, October to May, the lake is frozen over. This allows a fluctuation in the fox population due to immigration and emigration across the ice. The breeding population for each year was determined in late May, as soon as the lake thawed. The young are born in early June and are counted in early July.

Total population counts were continued for six full years. These counts were always made in late September by elaborate trapping methods. Immigration and emigration counts were determined by tagging the foxes as they were trapped and counted.

In September of 1958 the total population of foxes was 27. In September of 1959 the population was 31 foxes. In the years from September 1959, to September 1964, the following data were compiled for each one-year period:

	9/59–9/60	9/60–9/61	9/61–9/62	9/62–9/63	9/63–9/64
Breeding population	20	14	8	22	41
Natality	24	17	16	26	59
Mortality	11	16	4	6	43
Immigration	1	0	7	16	3
Emigration	9	5	3	6	15
TOTALS	25	10	24	52	45

From the above data, compute the total population for each year and complete the following questions:

1. Plot your computed populations on the graph for each year and then complete the graph by drawing the line from point to point.
2. What was the density of foxes in September of 1960?
3. From September 1961, to September 1963, there is a rise in population; however, you notice that there is a very high rate of mortality during the same period of time. Can you offer a valid conclusion about this high mortality rate? What would the graph probably look like if the population studies had been continued for 10 more years?

STUDENT-DRAWN GRAPHS.

Another way to test for understanding of graphs is to require the students to devise a graph. For example, students could be given these instructions: "Graph below the rate of expansion of copper for temperatures −10°C to 100°C" or "Draw a graph showing the rate of absorption of the red wavelengths of light in water."

Statistics

Several of the modern science curricula develop statistical concepts such as determining averages and experimental error, and making correlations, etc. Since these concepts are important in understanding science their achievement should be evaluated also.

GENERAL CONSIDERATIONS IN TEST CONSTRUCTION

This section contains some suggestions for constructing tests. These are not exhaustive, but they are fundamental for any test constructor.

True-and-False Test

If the examination is limited to true or false, seventy-five or more items are needed, statistically, to overcome the guessing factor. On a 100-question true-or-false test, students should be able to get about fifty questions right without knowing anything about the subject if they just guess. Some instructors help to eliminate this problem by subtracting the number of wrong answers from the number of right answers to determine the score and penalize for guessing. This procedure is not recommended because students usually think the instructor is using this technique for malicious reasons. It is undesirable also because the student is penalized for guessing. In science we wish to have students make hypotheses—good guesses.

Avoid overbalancing the test with too many true-or-false questions. Try to have these fairly even in number. This prevents a student who knows little about the material from getting a high score simply by assuming that more questions are true (or false).

Avoid using statements that might trick students.

Don't use the same language found in the text. This suggests to students that they should memorize.

Don't use double negatives in a statement. For example, do not write "Methane does not have no hydrogen in its molecule."

Avoid ambiguous statements. For example, do not write "Erosion is prevented by seeds."

Avoid using complex sentences in your statements.

Don't use qualitative language if you can possibly avoid it. Do not write, for example, "Good corn grows at a slower rate than hybrid corn," or "The better metals conduct electricity faster."

Arrange your statements in groups of ten to twenty. This helps to relieve tension for those taking the test.

Place the responses for answering the questions on one margin so that they can be easily checked by using a key.

Multiple-Choice Test

A multiple-choice test is made of items having more than three responses. If there are not at least four possible responses to each question, a correction formula should be used. A multiple-choice test differs from a multiple-response test in that only one answer is correct for each question in the former type of test.

In a multiple-choice test, make all responses plausible.

All answers should be grammatically consistent.

Attempt to keep all responses about the same length.

Randomize the correct answers so that there is no pattern in the examination. Students often look for a pattern.

Remember that the correct response often can be arrived at by a process of elimination as well as by knowing the correct response. Try to prevent this in your phrasing of the answers.

Present first, in the question, the term or concept you wish to test for.

Test for the higher levels of understanding as much as possible.

Require a simple method for the response. Place the space for the answers all along one margin of a page, so that they can be easily keyed. This can be done by providing short lines on the margin.

Group your items in sections. This makes it easy to refer to various sections of the test and helps break monotony in taking the test.

Group together all questions with the same number of choices.

Completion and Matching Tests

Completion and matching tests usually emphasize recall and are often verbally tricky. For this reason they should be avoided.

If matching questions are used, they should be grouped. When there are more than fifteen matching items in a group, the test becomes cumbersome.

Number your questions and use letters for your answers, or the reverse; but be consistent.

Although matching tests have traditionally stressed simple recall, they can be used to test for recognition or application of principles. Three sample matching questions follow:

Questions	*Answers*
___1. A machine which would require the least amount of friction on it to move it 20 feet.	a. Pliers b. Wheelbarrow c. Ice tongs d. Seesaw
___2. A machine which could best be used to pry open a box.	e. Doorknob f. Pencil sharpener g. Saw
___3. Which of the listed devices is made up of the greatest number of simple machines?	

Self-Test

A self-test is similar to any other test in its construction, but it is taken by the student mainly as a learning device. It usually has questions on one side of a page and the answers on the other side. The student takes the test; then he turns over the page and checks his answers. The instructor can use the completed test as a means of stimulating discussion.

Teachers usually set up self-tests on ditto masters and run off enough copies for their students. A suggested format is shown in Figure 32. The back page should contain a detailed explanation for each answer so that students learn from the test. The student folds under the answers on the right side of his page. The answers then are next to the correct answers and explanations on the *left* margin of the back page. This makes it easy to correct the test.

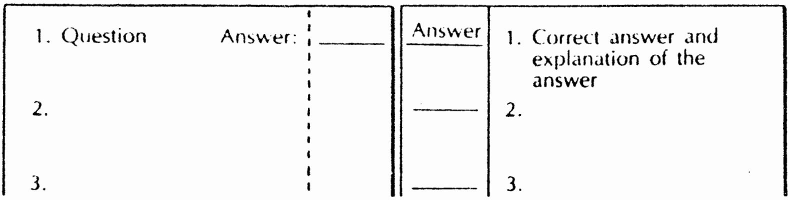


Figure 32

A Problem Test

This kind of test presents a problem and asks the students to work on it. It is similar to an invitation to inquiry except that it is done by an individual student. The test usually contains a series of questions the students are supposed to answer in solving the problem. A problem test can be constructed with relative ease if it is based on a problem that has actually confronted a scientist. These problems can be easily obtained from a scientific journal. Give the students information about the problem and have them devise their own hypotheses, research designs, or methods of collecting and recording data. A problem test can best be used to acquaint students with scientific processes. The test may have an answer sheet similar to that for a self-test, or it may be used to stimulate discussion. Scientific problems which are open ended in nature are preferable for this kind of test.

Some examples of problems that might be used in constructing a test of this nature are given below:

1. How would you reduce the amount of pollution from a smoke-stack?
2. A citizen thought the local river was polluted; how could he find this out? What experiments could he do?

3. A scientist thought a fungus might produce a chemical that inhibits the growth of bacteria. What kind of experiments would he need to do in order to verify his hypothesis?

Student Correction of Tests

Student correction of tests can be done in several ways. A student can act as an aide using a key prepared by the instructor to correct the tests. An instructor can pass the tests out to students at random, read the answers to the class and have them correct and compute the scores. Another approach is to give the students a key after they have taken the test. The students then correct their own tests. For answers they missed, they should write on the back of the test or on a separate paper an explanation for their incorrect responses. These can be analyzed and other item analyses made to determine the questions that should be modified or eliminated in future testing.

SELF-EVALUATION INVENTORIES[5]

Description of Self-Evaluation Inventories

A self-evaluation inventory (SEI) is an instrument enabling students to rate their progress toward attainment of objectives in a course, a unit, or a daily lesson. The instrument consists simply of an item sheet containing behavioral objectives of a teaching unit and a response sheet. The response sheet is composed of nine point scales—one response for each objective included on the item sheet. Three descriptions representing different levels of achievement are equally distributed along each scale.

Students evaluate their gain in knowledge and skill by placing two marks on each scale, one representing their achievement level at the beginning of the unit of instruction and the other representing an estimate of their achievement level at the end of the unit of instruction.

In the following example, a student has used the letter "B" to represent his knowledge level for an objective at the beginning and an "E" to represent his knowledge level at the end of the unit of instruction.

Low				Moderate				High
	B					E		
1	2	3	4	5	6	7	8	9

[5]This self-evaluational material has been largely prepared by Dr. Clifford A. Horwolt of Minot State College, Minot, North Dakota.

The numerical difference between the two marks, called the *item gain score*, represents the gain in knowledge or skill implied by a specific objective. The sum of all the item gain scores on a self-evaluation inventory, called the *gain score*, represents the gain in knowledge perceived by the student for a particular set of objectives.

For validation of the SEI, criterion tests constructed from the same course objectives have been administered by investigators in pretest and posttest situations. A correlation between the gain scores of the self-evaluation inventory and the gain in achievement, as measured by the criterion test, has been found to be significant (Duel, 1956; and Tillery, 1967). A significant correlation indicates students have made accurate self-judgments about their gain in achievement pertaining to the unit of instruction.

Use of Self-Evaluation Inventories

Self-evaluation inventories have many uses in education. Among those used previously are student evaluation of teacher effectiveness, course evaluation, final grades, and teacher self-rating of effectiveness.

Only recently has emphasis been placed on allowing students to make self-judgments about outcomes that deal with them individually in a course of instruction. Self-evaluation inventories can be used in daily lessons, a unit of instruction, or a course of instruction. They can be used to evaluate objectives in relation to films, field trips, laboratory exercises, and individual items contained in a multimedia approach.

Students can make self-evaluations on cognitive achievement or on a variety of dimensions within the affective domain: interest, attitudes, values, appreciations, and relevancy. Self-evaluation is only as good as the quality of the inventory.

Construction of Student Self-Evaluation Inventories

The first step in the construction of a student self-evaluation inventory is to decide what goals to evaluate for a lesson, a unit of instruction, or a course of instruction. Next, write specific behavioral objectives for goals of instruction. These objectives should include cognitive, affective, and psychomotor domains.

Once the behavioral objectives have been written, place them on the item sheet. Order the objectives according to subject or cognitive level, i.e., light, sound, waves, or knowledge, comprehension.... evaluation.

The construction of the response sheet may vary with the interest of the evaluator. If only content (achievement) is to be evaluated, place a six or nine point scale for each objective on the response sheet.

The scale should be on a continuum from low to moderate to high. Other scales for evaluation of interest, value, or relevancy may be included along with the content scale for each objective.

Administration of the Inventory

Two methods of administering self-evaluation inventories can be used. These two methods are:

1. *Same time*: The inventory is given only at the end of the period of instruction. The student rates his "before and end" achievement at the same time. This method is desirable on a daily lesson.
2. *Pre-Post*: The inventory is handed out at the start of the unit of instruction and the student rates his "before" achievement on the response sheet. The response sheets are collected and the unit of instruction then takes place. After the instruction, the response sheets are handed back to the student and he makes his "end" achievement evaluation. This method may be more desirable on a unit of instruction covering a larger period of time, e.g., two-week unit or a ten-week course. The student should be allowed to retain the objectives throughout the unit of instruction.

Sample SEI Illustrating Method of Same Time

STUDENT SELF-EVALUATION INVENTORY

Instructions: You are requested to indicate for the following series of items your opinion of the degree of skill or knowledge you possess in each case. Evaluate items in terms of the scale shown. Place two letters on the scale of the response portion for each item. A "B" should be used to indicate the amount of skill or knowledge you had at the beginning of the lesson. An "E" should be used to indicate the degree of skill or knowledge you now have at the end of the lesson.

ITEM	*RESPONSE* Low			Moderate			High		
1. *Identify* from examples the specific properties of the state of matter involved.	1	2	3	4	5	6	7	8	9
2. *Propose* examples to illustrate the properties of gases, liquids, and solids.	1	2	3	4	5	6	7	8	9
3. *Graph* the relationship between volume, temperature, pressure of gases when one variable is held constant.	1	2	3	4	5	6	7	8	9

ITEM	*RESPONSE* Low			Moderate			High		
4. *Apply* volume, temperature, and pressure relationships to a balloon which moves up and down in the atmosphere to determine size relationships.	1	2	3	4	5	6	7	8	9

For futher information on the justification for using self-evaluational inventories in science consult:

Clifford A. Hofwolt, "An Exploratory Study of the Effect of Self-Evaluation Inventories on Student Achievement in High School Science Courses," Ed. D. dissertation, University of Northern Colorado, 1971.

James H. Duel, "A Study of Validity and Reliability of Student Evaluation of Training," Ed. D. dissertation, Washington University, 1956.

Tillery, Bill W., "Improvement of Science Education Methods Courses Through Student Self-Evaluation," Ed. D. dissertation, Colorado State College, 1967.

NATIONAL ASSESSMENT PROJECT IN SCIENCE

A group of educators beginning in 1964 established an Exploratory Committee on Assessing the Progress of Education. As the work progressed and more individuals became involved in the project it became known as the Committee on Assessing the Progress of Education. In 1969, the Education Commission of the States took an active part in the work of the committee and implemented the first National Assessment in Science as well as other areas.

Educational Testing Service was responsible for formulating the behavioral objectives and examination questions. The preparation and review of these involved many science educators, scientists, and lay persons.

Partial reports of the first year of assessment in Science and Citizenship were released in July 1970. Science knowledge, understanding, and skills were evaluated for ages nine, thirteen, seventeen, and young adults. Anyone interested in science instruction and evaluation should obtain a copy of the report from the Education Commission of the States:

822 Lincoln Tower 1860 Lincoln Street Denver, Colorado 80203	OR	Ann Arbor Office Room 201 A Huron Towers 2222 Fuller Road Ann Arbor, Michigan 48105

The Report is entitled *National Assessment of Educational Progress, 1969-1970 Science: National Results and Illustrations of Group Comparisons*, July 1970.

Some examples of principles young adults were tested for and the percent answering them correctly are shown below:[6]

403. The movement and characteristics of air masses are important in predicting weather (85%).

404. A malady that cannot be inherited is whooping cough (79%).

405. Sterilizing an adult human male by "tying off" his main sperm ducts will not result in any of the following: 1) his voice becoming higher pitched, 2) fatty pads on his hips, 3) effeminate behavior, or 4) longer growth of hair (72%).

406. Adrenaline acts as a stimulant (70%).

407. In mammals sperm is produced by the testes (67%).

A good many young adults responded correctly that:

408. A fuse is placed in an electric circuit to make the circuit safer (64%).

409. The theory of evolution, through natural selection, is associated with Charles Darwin (63%); 30% responded I-don't-know.

410. An electric current in a copper wire involves mainly the movement of electrons (63%). About 30% responded I-don't-know.

411. Flower seeds develop from ovules (62%).

412. Physical rejection of an organ transplanted is least likely if the donor is an identical twin (60%).

413. Most of the chemical energy of the gasoline burned in a car is converted to heat (60%).

414. Salt carried by the rivers to the oceans comes from beneath the ground (57%).

415. If a motor boat which can travel 5 miles per hour on a still lake travels downstream on a river that is flowing 5 miles per hour it take the boat 60 minutes to reach a bridge that is 10 miles downstream (56%).

416. The egg of the human females is released about 14 days after menstruation begins (55%).

417. One could increase the total amount of food available by outlawing insecticides (55%).

418. The longer a rock falls, the greater is its speed (51%).

419. The molecules of hot water are moving faster than the molecules of cold water (49%). Over 30% responded I-don't-know.

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[6]Education Commission of the States, *National Assessment of Educational Progress, Report I, 1969-1970 Science: National Results and Illustrations of Group Comparisons*, 822 Lincoln Tower, 1860 Lincoln St., Denver, Colorado 80203, July 1970, pp. 119-121.

420. Placenta in a pregnant human female carries nourishment to the baby (45%).
421. If a person who is a light eater has a tendency to be overweight, it is most likely due to highly efficient utilization of food by the body (45%).
422. Most caves are formed by the action of underground water on limestone (42%).
423. The system of classifying plants and animals that is most commonly used in the biological sciences is based primarily on structure (42%).
424. Bacteria do NOT play a key role in photosynthesis (40%); 24% responded I-don't-know.
425. If a fossil of an ocean fish is found in a rock outcrop on a mountain it probably means that the mountain was raised up after the fish died (39%).
426. The chief difference between solid, liquid, and gaseous states of water is the speed with which molecules are moving (37%). Over 50% responded I-don't-know.
427. In mammals the cerebrum is the center of memory and intelligence (36%).

Rather few young adults responded correctly that:

428. If a man whose blood type is OA marries a woman whose blood type is OB, their offspring could NOT have AA blood type (31%); 50% responded I-don't-know.
429. The table showing relations among all the chemical elements is called the periodic table (26%); 45% responded I-don't-know.
430. If two light waves are travelling in a vacuum the wave with the higher frequency will have the shorter wavelength (22%). Over 40% responded I-don't-know.
431. The amount of DNA is identical in a mature egg cell and sperm cell within the same organism (21%). Over 65% responded I-don't-know.
432. The atomic weight of titanium is 48. This means that the average mass of titanium atoms is approximately 4 times the mass of the atoms of a certain carbon isotope with atomic mass 12 (16%). Over 70% responded I-don't-know.
433. Scientists can determine the age of certain rocks and their fossils by measuring the amounts of uranium and lead they contain (15%). Over 30% responded I-don't-know.
434. Uranium-lead dating has been used to obtain accurate estimates of the age of the oldest known rock strata (3%). Over 40% responded I-don't-know.

Although the National Assessment Project is in its infancy, it has released certain characteristics about science achievement as shown below:

1. Science understanding, knowledge, and skills increase progressively for the ages tested, 9, 13, and 17, but not for young adults.
2. The Northeast part of the country 17 year olds did 6% better in achievement while the Southeast did 5% less well compared to the total sample for this age group. There was close to zero differences between the Central and Eastern parts of the U.S.
3. Males did better than all 17 year olds on tests for this age group.
4. Nonblack 17 year olds' achievement was 11% better than for blacks.
5. Seventeen-year-old students whose parents did not complete high school were 8% poorer in achievement tnan those coming from high school graduate parents.[7]

INCREASE THE USE OF DIAGRAMS OR PICTURE TYPES OF TESTS

Most science tests evaluate more for reading than they do for science. Many students understand the science principles but because they have verbal difficulties, such as reading and interpreting what they have read, they do poorly on tests. Studies indicate that a marked number of students do significantly better on tests consisting mainly of pictures and requiring them only to check the correct responses.[8] The BSCS, in preparing a special course in biology for the mentally retarded, found when evaluating achievement by using 35 mm. slides that both the teachers and specialists were amazed at how well the students did.[9]

Refer to the following tests used in the National Assessment and choose the item you think discriminates verbally the least. Study the format of this question. Practice preparing similar pictorial items yourself. Refer to the chapter on discussion having to do with pictorial riddles. How could you change a riddle into an evaluation item?

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[7] *Ibid.*, p. 151.

[8] Leonard B. Finkelstein and Donald D. Hammill, "A Reading-Free Science Test," *The Elementary School Journal* 7 (October 1969): 34-37.

[9] Richard R. Tolman and James T. Robinson, "Formative Evaluation of Unit 1, Digestion and Circulation," *BSCS Newsletter*, #43, 9 (1971): 7.

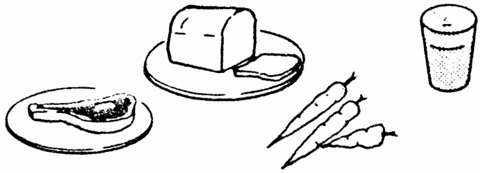
OVERLAP EXERCISE 13[10]

6% difference in favor of age 17

(13: 7-11, 17: 6-3) (also 204 and 302)

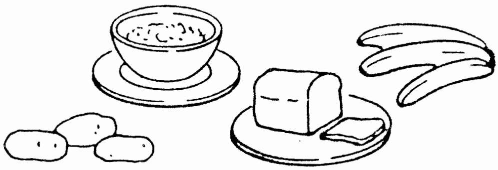
Which of the following would most closely represent a balanced meal?

Age 13 *Age 17*

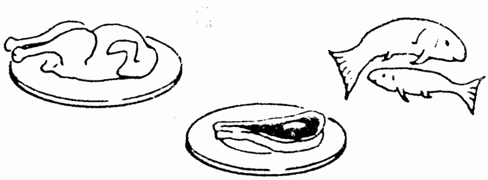


89% 95% Steak, bread, carrots, and milk

1 0 Ice-cream soda and cake



5 3 Potatoes, oatmeal, bread, and bananas



3 1 Poultry, steak, and fish

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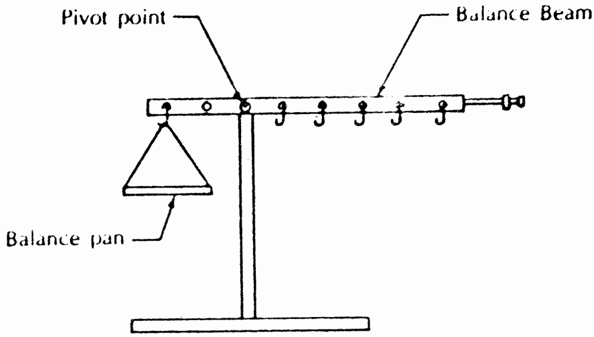
[10]Education Commission of the States, *National Assessment*, pp. 35, 38, 86, 134.

1	1	Hamburger and coke
0	0	I don't know
0	0	No response
99%	100%	

OVERLAP EXERCISE 22

1% difference in favor of age 17

(13: 13-21al, 17: 14-12al, Adult: 10-21al)
(also 234, 341, and 438)



The apparatus before you is the same as that shown in the picture. This balance is balanced when the balance beam is level as shown above. The number by each mark on the beam tells the number of inches that mark is from the pivot point.

1. Place one weight in the balance pan. How many inches from the pivot point is the hook on which you must hang one weight to get balance? (4)

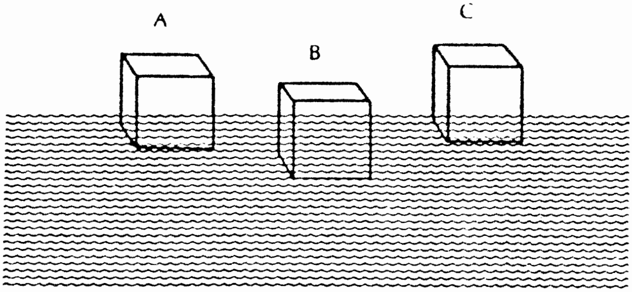
Age 13	*Age 17*	*Adult*	
64%	75%	74%	Correct
34	22	20	Incorrect
2	2	6	No response
100%	99%	100%	

The apparatus also included fishweights, one to place in the balance pan, and another to use to achieve balance. The respondent was given

20 minutes to find the answer to this and other questions involving the use of the apparatus (see Overlap Exercise 21).

EXERCISE 232

(13: 5-13)

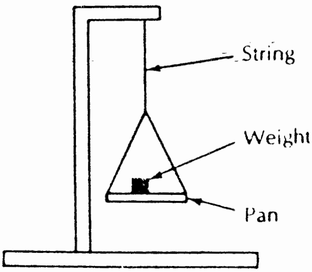


The three solid objects shown above have the same volume. If they float as shown in the diagram, which one weighs the most?

Age 13	
0%	Object A
75	Object B
4	Object C
6	They all weigh the same.
14	It is impossible to tell without additional information.
1	I don't know.
0	No response
100%	

EXERCISE 441

(Adult: 10-21cl) (Overlaps exercises 237 and 344)



The apparatus before you is a pendulum. You have a watch or clock also.

1. How long does it take for the weight in the pan on the end of the string to swing back and forth ten times?
   ___ seconds (An answer between 11 and 15 seconds was scored correct.)

   Adult

49%	Correct
39	Incorrect
12	No response
100%	

GENERAL GUIDELINES TO USE IN TESTING

1. Use tests humanely as learning and diagnostic devices. Give students opportunities to demonstrate they have learned what they missed on a test and improve accordingly their grade.
2. Never use a test as a punishment.
3. *Avoid* using *completion* and *matching* questions.
4. Use tests or self-evaluational inventories to evaluate all of your behavioral objectives, including the science processes and attitudes.
5. Spend time with each student going over the questions he missed. This may be done while the class is involved in doing laboratory work.
6. Remember that tests are only a sample of what has been learned and probably not a very good one. They should, therefore, not be used as the only means of evaluating. Take into consideration all the things students have done in class to develop their multi-talents.
7. Test for all levels of Bloom's Taxonomy and use a test analysis grid to see that this has been done.
8. Ask questions to determine how students feel about the material being used.
9. Place the easier questions at the beginning of the test so students gain confidence and minimize their frustration and nervousness.
10. Consider the time factor. How long will it take students to complete the test? Some students will finish much sooner than others. What will you do with them? If you do not have some work outlined, they are likely to present discipline problems.
11. Design the test to be easily scored. Place a space for all the answers on one margin.

12. Rather than have students write on the test have them place their responses on an answer sheet. This insures ease of recording and saves paper since the test may be used for more than one class.

Discourage dishonesty. Attempt to remove the temptation to copy by spreading students out or by making two versions of the same test and alternating these when you pass out the tests. You may wish to try the honor system; some instructors in high school have used this with success. Caution the students as soon as you see anyone cheating. It generally is better not to mention the name of the culprit at the first infraction. You might just say, "I see cheating" or "Some people are stretching their eyeballs." If you really stress honesty in the first tests your task of trying to prevent dishonesty will be lessened during the rest of the term. Set a pattern of honesty immediately in your classes. Be present while students take tests, and discipline a pupil if he is guilty of continued dishonesty.

SUMMARY

Evaluation involves the total assessing of a student's learning by the instructor. Science teachers evaluate students mainly by tests and laboratory reports. Just as there are levels of learning so are there levels of testing.

Modern teacher-made tests should stress the higher cognitive levels of Bloom's taxonomy and the affective domain more than they should stress recall questions. Tests should be constructed from an instructor's list of behavioral objectives so that he evaluates what he considers most important in the learning process. A test is only a sample of what is being learned. Other means of evaluation also should play a major part in determining the achievement and development of the students' multiple talents. Self-evaluational instruments should be used frequently in assessing a student's achievement. The student is best able to determine what he is learning and how he feels about it. Teachers need to ask students to judge their own achievement. One way to do this is to give the students a list of behavioral objectives over a unit or course and have them judge what they knew or felt about the course before studying the material compared to after. This method has been shown to be a valid measuring technique and gives a better indication of actual growth than does the typical test.

Because mathematics and graphing are so much a part of science, tests should incorporate many graphs and mathematical data. A good technique to use to see whether students understand graphing is to have them complete a graph or devise one.

Each test should contain questions that will enable the teacher to evaluate students' understanding of the methods of science. Students should know how to recognize a problem, make hypotheses, interpret data, draw valid conclusions, and devise experiments.

Certain features of each type of test must be considered before tests are constructed. Completion and matching tests, because of their emphasis on recall, are to be discouraged. Self-tests and problem tests place more emphasis on self-instruction and can be used to motivate class discussions. A teacher should consider how long a test will take and should provide assignments for those who finish before the class ends. The incidence of discipline problems is lessened in this way. Cheating must be strongly discouraged early in the term.

Good test construction requires considerable sophistication if sole dependence upon memorization is to be discouraged; therefore, teachers are urged to get further training in this very important part of their professional competence.