A sound theory base for science education must include educational purpose, the discipline of science, and a model for learning.

**Educational Purpose.** The purpose the schools serve has been the subject of many essays, much debate and a great deal of controversy. None of those polemics--with one exception--will be described here. The exception is the 1961 statement of the Educational Policies Commission (E.P.C.) which succinctly stated that the central purpose of education is to teach students to think. That mission was spelled out by the E.P.C. in the essay *The Central Purpose of American Education:*

...The purpose which runs through and strengthens all other educational purposes—the common thread of education—is the development of the ability to think. This is the central purpose to which the school must be oriented if it is to accomplish either its traditional tasks or those newly accentuated by recent changes in the world. ... Many agencies contribute to achieving educational objectives, but this particular objective will not be generally attained unless the school focuses on it ... (Educational Policies Commission, 1961, p. 12).

The authors of the document wished readers to attribute to "central" the meaning "the center of." The responsibility of every school activity in which students engage should be leading students to develop their thinking abilities. According to the E:P.C., the school is an intellectual institution, and developing the intellect of the students is its central responsibility.

The E.P.C. went beyond what has just been said and operationally defined thinking as the rational powers of the free mind and lists those powers as recalling, imagining, classifying, generalizing, comparing, evaluating, analyzing, synthesizing, deducing, and inferring. If, therefore, science education is to contribute to the achievement of the central purpose of education, its curriculum must provide experiences which lead students to use the rational powers. It is through the use of their rational powers that students develop and refine those thinking abilities. How are rational powers developed using the discipline of science?

**Science.** Albert Einstein stated his understanding of the discipline with this statement: "The object of all science is to coordinate our experiences and bring them into a logical system" (Holton & Roller, 1958, p. 214).

If Einstein's life's work is reviewed, it is obvious that he did coordinate his experiences and thoughts and did bring them into a logical system. The inference could be made from Einstein's description that science concepts—what teachers teach—come from the ordering, coordinating, and the making of the logical system. But the logical system which emerges is not, alone, science. It is the construction— the searching, questioning, and ordering to form the logical system—that is science.
The French scientist and mathematician Henri Poincare said: "The scientist does not study nature because it is useful; he studies it because he delights in it, and he delights in it because it is beautiful" (Holton & Roller, 1958, p. 237.). Poincare explained that the beauty he is concerned with was a "beauty which comes from the harmonious order of the parts. . ." It is that order which, according to Poincare, gives science "body, a structure so to speak. . .". Quite evidently, Einstein's "logical system" and Poincare's "harmonious order" are two labels for the same idea. Poincare gave a fuller description of the meaning of his harmonious order when he said (Kelly, 1941, p. 240):

Science is built up with facts as a house is with stones, but a collection of facts is no more a science than a heap of stones is a house.

Science, then-according to Poincare-is seeking the harmonious order among the facts in order to release the beauty of nature. The seeking of Poincare and the coordination of experiences by Einstein are describing science as an intellectual activity about nature and not merely a collection of natural facts.

Niels Bohr offers this description of the discipline of science (Holton & Roller, 1958, p. 214):

The task of science is to both extend the range of our experience and reduce it order.

Einstein's building a logical system, Poincare's establishing harmonious order, and Bohr's reduction of experience to order are all saying the same thing. Science is not only the facts, principles, generalizations, and laws, but finding and ordering the data from our experience which lead to facts, principles, generalizations, and laws.

The word "experience" is found in the descriptions of science given by Einstein and Bohr and implied in the Poincare description. But what does one experience in pursuing the study of science? The scientist experiences a quest and that quest has two phases. The first phase concerns the gathering of data relative to the phenomenon under consideration, the actual interaction with the physical world. The second phase involves questing among the data gathered to establish relationships. Einstein described the second phase as bringing the data into a logical system, Bohr explained this second phase as reducing the data to order, and Poincare referred to it as putting the data in harmonious order. If students are to be led to become scientifically literate they must experience both phases of the discipline.

Duane Roller, Historian of Science, was precise in his description of science when he said (1970, p. 23):

“…science is the quest for knowledge, not the knowledge itself.”

The conclusion which can be drawn from the foregoing descriptions of science is that if science is to be taught in classrooms, students must participate in making observations; taking measurements; and collecting, organizing, and interpreting additional data. Those activities will lead the students to the facts, principles, laws, and generalizations which scientists have established, but just learning and/or memorizing...
those facts, principles, laws, and generalizations is not participating in science.

What do students do when engaging in a quest for knowledge? They use their imagination in assembling the equipment and/or using the materials; data which are obtained are analyzed, compared, evaluated, and classified. Inferences are made and probably tested deductively, and generalizations are synthesized. In other words, students engaging in a quest for knowledge-science-are given multiple opportunities to use and develop their rational powers—the essence of the ability to think. Those students have, therefore, achieved the central purpose of American education, and science, taught as a quest, has been shown to be a proper curricular element to use in leading students to achieve that central purpose.

Students and Learning. Students need guidance while learning. Research (Marek, 1986a; 1986b) has shown that putting students and the content of science together without structure would undoubtedly result in learning, but of what? Misconceptions? Partial understandings? Students must be led to learn the concepts of the science disciplines; in other words, students construct their own knowledge with guidance from the teacher. But this construction of knowledge by the students requires teachers to "teach" science differently than it is "taught" in most classrooms. Research has shown (Harmes & Yager, 1981) that 90 percent of all teachers use a textbook 95 percent of the time. Textbooks (and/or teachers) generally inform the students what they should know about a scientific phenomenon or concept. If a laboratory is part of the course, that experience usually permits the students to verify the concept about which they have been informed. Next, questions are answered, problems are solved, and some other form of practice is usually provided. The inform-verify-practice (IVP) teaching procedure is satisfactory if the school's purpose is to present information about science. In the IVP procedure the "quest" element, however, is missing. In science classrooms where the IVP procedure is used, student learning is viewed as being dependent upon some authority providing the students with the correct information. Perhaps the assumption is made that the students cannot construct their own knowledge about science from their experiences (and the IVP teaching procedure does not give them that responsibility).

Assume that students can construct their own knowledge from their experiences. What experiences should they have? The first experience needed deals with making investigations using materials which will produce data from which a concept can be constructed. Suppose, for example, that the following concept is to be taught.

A electrical circuit consists of an energy source, an energy receiver, and wires connecting them.

Students could be given wires, dry cells, and flashlight bulbs; the students would then use those materials and during their explorations find out how the bulb is connected to the other elements to produce light. Eventually the teacher will ask the students what is necessary to make the bulb light and the students—or teacher—will assign labels such as energy source and energy receiver to the elements of the system. At this point the teacher tells the students that they are working with an electrical circuit. In other words, the teacher leads the student to invent the concept of electrical circuit from their data. Think back to Einstein's description of science. The students have had experiences with the elements of an electrical circuit and the teacher has assisted them in bringing those
experiences into a logical system. The logical system is the concept of electrical circuit which has been *invented* by the students. Students have experienced science-Einstein's description of science has been implemented.

The next phase of learning science deals with *expanding the concept* of electrical circuit to other circuit types. Series and parallel circuits can now be approached by letting the students use dry cells, bulbs, and wires to find the similarities and differences among those circuit types, and proper verbal labels can be introduced. The phases of *exploration, conceptual invention, and expansion of the concept* are called the *learning cycle*, which represents not only a teaching method but also a curriculum development procedure. Selecting activities to be used to produce data from which a concept can be invented is quite different than the IVP procedure of telling the students the concepts before giving them materials and/or apparatus to verify what they have been told.

**A Learning Model.** What model of learning supports the learning cycle? The developmental learning model of Jean Piaget (Piaget, 1973; Inhelder & Piaget, 1969, p. 6; Renner & Marek, 1988, Chapter 2) explains that learning—or mental functioning according to Piaget—begins with *assimilation*. That process is responsible for letting the students collect data during the learning cycle's exploration phase from which concepts can be invented; those inventions are accommodations in the mental functioning model. When the newly invented concept is used in another setting the concept is said to be *organized* with other concepts in the same general academic area; in other words, the concept's meaning has been expanded. Thus *assimilation, accommodation, and organization* represent a learning model upon which the learning cycle teaching and curriculum-development procedures are based. Furthermore, assimilation and accommodation represent the "experience" and "logical system" elements in Einstein's description of science and are the essence of a quest. The organization phase of the mental functioning model represents an extension of the logical system idea which enables us to utilize our knowledge as an integrated whole.

What motivates students to follow the learning cycle to its conclusion? Perhaps it is the grade the student will receive on the particular piece of work being done or the grade he/she will receive at the end of the semester. There is, however, another reason which works to an advantage in the learning cycle. Students, according to the Harmes and Yager research referred to earlier, are accustomed to having answers readily available, because "the book" can generally be relied upon to provide answers. The absence of readily available answers causes the students to ask such questions as "Why did that happen?" "Will that event happen again?" "What can be done to change the results of that process?" In addition, many more specific questions will be asked. An example of such a specific question is, "Why did that solution change color?" Such questions represent an interpretation of what Jean Piaget calls *disequilibrium*. Disequilibrium is a questioning state which is brought about by what has been assimilated. Equilibrium is reestablished when adjustments are made between what was known before the assimilation and new ideas which emerge from the assimilation; that adjustment process is accommodation. The learners have now accommodated themselves to a new idea and that new idea must be organized with other knowledge the learners possess. In other words, learning a new idea is concluded by the *organization* process (Piaget, 1970).

**Students and Content.** The intellectual stage model of Piaget has generated some controversy. Regardless of the various polemics engaged in, one factor is clear-
intellectual growth does occur and it happens at several successive levels. Furthermore, no level is omitted, even though the amount of time a particular person spends within each individual stage may vary. In addition some of our work (Stafford & Renner, 1971) has shown that the type of educational experiences students have can influence the amount of time required for them to pass through one stage and into another.

The names of the intellectual stages—sensory-motor, pre-operational, concrete operational, and formal operational—are well known. The descriptions of those stages will not be repeated here because many references are available (for example, Renner & Marek, 1988, Chapter 1). There is one factor that our research (Renner & Marek, 1988, pp. 19, 25) has made clear. Concrete operations are entered gradually, with complete achievement being reached about the age of ten years. Basing our work on the data from interviews of 811 tenth, eleventh, and twelfth graders, only approximately 23 percent of secondary school students are completely formal operational by the completion of high school.

Our work (Lawson & Renner, 1975) has enabled us to divide content into two categories. One category consists of concepts which both concrete and formal operational students can learn and the second category contains concepts which can be learned only by those students who are intellectually on the formal level. The first concept category has been called concrete concepts and the second formal concepts. The work just referred to enables this hypothesis to be offered: those students who think on the concrete level do not learn formal concepts.

Research done by Cantu and Herron (1978) supports this hypothesis. Those researchers found as did we—that formal operational students learn more concrete concepts than do concrete operational students. Cantu and Herron said:

"We see no theoretical basis for belief that formal-operational students should be able to learn concepts that have perceptible examples and attributes (concrete concepts) better than concrete operational students—assuming, of course, that the strategy used to teach the concepts does not rely on formal reasoning. We designed lessons to test this hypothesis and found that the hypothesis was not supported. Our data clearly indicate that formal-operational students learn more, even when the lessons are over concrete concepts.

We are not entirely discouraged by this result. Concrete-operational students did learn two of the concrete concepts rather well, even though not as well as the formal students. (Concrete-operational students did not learn any of the formal concepts very well.)"

The foregoing quotation supports our research in two ways. The data of Cantu and Herron recognize that science concepts can be learned on two levels—concrete and formal—and that concrete operational students do not learn formal concepts "very well." The research cited suggests that the intellectual similarities between the students and the content need to be considered when preparing curricula.

There is a need for an educational theory base for science teaching. That theoretical basis for science teaching could be based upon educational purpose, a developmental model of learning and the structure of the discipline of science. Based
upon the information provided in this article, it is apparent that the content of science and its process structure need to be considered with great care.

References


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