

Problem solving

In the September issue, Robert Fuller (page 43) uses both the information-processing and the constructionistic models to illustrate how a physicist might solve physics problems. I would like to add two points concerning the constructionistic model of problem solving. Basically, the constructionistic model proposes that the "'Laws of Nature' are built at the interface between our sensory experience and our reasoning about those experiences" (page 47). The model proposes that we receive the input from our senses and structure our interpretation of these phenomena according to certain preconceptions.

First, I would like to mention a strong source of scientists' preconceptions that was not covered in the article but that guides scientists' selections of suitable research problems, their expectations, and interpretations of results. This source of the scientists' preconceptions is the structure of science. Research and teaching in science are based on scientists' acceptance of certain theories of nature. Both focus on these theories and the phenomena that these theories describe. Thus, a scientist has a view of nature, a research problem and expectations of the results that follow from these accepted theories.

Second, individuals have one more option for reducing cognitive conflict than is mentioned in the Piaget assimilation-accommodation-equilibrium model. According to Festinger (1957), they can mentally discount external occurrences which conflict with their preconceptions. In other words, scientists are not bound to stop believing in the accepted theories even if their experimental results refute them. Scientists, like other people, have the cognitive option of mentally dismissing the data and continuing to believe in the theory, their preconception. This option is one of the reasons why deficiencies in the currently accepted theories are not always immediately brought to the attention of the scientific community. This cognitive option indirectly affects the progress of science by permitting the mental dismissal of evidence which might have led to the information of a more elegant theory.

The theories in a given field are an important source of the scientist's conceptions about nature. Kuhn, a historian of science and a physicist, has proposed that a group of scientific practitioners follow an orientation, a paradigm, which they have found useful in solving those problems which

they recognize as acute¹. For example, the beginnings of some paradigms might be Aristotle's analysis of motion or Maxwell's mathematization of the electromagnetic field. Kuhn proposes that the majority of science consists of articulating the phenomena and theories that the paradigm supplies. This work may include clarifying the paradigm, testing its predictions in new areas, or striving for greater accuracy in defining the class of phenomena which the paradigm has shown to be revealing of the nature of things. For example, the specific gravities and compressibilities of materials, wave lengths and spectral intensities, and electrical conductivities and contact potentials have all been important to a physics paradigm at one time or another. Kuhn believes that the extraordinary breakthroughs occur rarely when the paradigm is recognized as failing in its ability to explain phenomena. The breakthroughs are likely to usher in a new paradigm and the cycle of scientific progress begins again with the majority of work being focused on the theories and phenomena that the paradigm supplies.

Scientists, as students, receive their socialization into the currently accepted paradigms and then are likely to be guided by them in their selection of a research topic and in their expectations of the results. As Kuhn notes, the problems that are based on the paradigms are the only ones likely to be accepted by the scientific community. "Other problems, including many that had been previously standard, are rejected as metaphysical, as the concern of another discipline, or sometimes as just too problematic to be worth the time." In sum, scientific paradigms are one of the greatest sources of scientists' preconceptions in interpreting the 'Laws of Nature' because they guide the selection of the research problem and expectations of results. In this way, paradigms direct the progress of a science.

Another factor that affects the progress of science is how the scientist interprets those experimental results that are in conflict with his or her expectations. Piaget's model proposes that when we obtain information that doesn't match with our mental schemes, we are disequilibrated and need additional information to modify our interpretations of the experience. Fuller states that we are led to seek additional experiences or to reorganize our thinking. He adds that this situation is where learning occurs. Certainly, there is the potential for learning under these conditions, and I might add for the progress of science in general, but the scientist does not have to change his beliefs in the paradigm to accommodate the new information.

Festinger's theory of cognitive dissonance² covers the possibility of individuals maintaining their preconceptions in the face of conflicting evidence.

A scientist has two options if further experimentation has failed to affect the results. He can accept the results and question the validity of the paradigm or he can mentally dismiss the experimental results and continue to believe in the paradigm. In both options, the conflict is between the body of knowledge the scientist has accepted and the perplexing results that have been verified by the scientific method, another part of the scientist's training. Festinger's theory predicts that the individual is likely to add considerations to one side to make it appear more attractive and, thus, resolve the dilemma of choice. Later, after the choice has been made, the chosen alternative will be viewed more favorably than it was prior to the choice. This change in viewpoint is another mechanism for reducing cognitive conflict.

Gradual scientific progress is based on the accepted paradigms that structure scientists' perceptions and direction of experimentation. Alternatively, the discovery of new paradigms depends on how scientists resolve their cognitive conflict when their results disagree with their preconceptions. Scientists are not limited to following the two options described by Fuller of gathering more data or changing their preconceptions to be in agreement with their experimental data. They have the cognitive option, as do all people, of dismissing the data and continuing to believe in the paradigm. It is this third option that is partly responsible for paradigms lasting for generations of scientists. Experimental results that could show deficiencies in the paradigm and hasten work in developing a more inclusive paradigm may have been mentally dismissed by the scientist. One would hope that the awareness of their own cognitive processes would help scientists deal with their unexpected results in such a way as to most benefit their respective fields.

References

1. T. S. Kuhn, *The Structure of Scientific Revolutions*, University of Chicago: Chicago University Press, 1963.
2. L. Festinger, *A Theory of Cognitive Dissonance*, Palo Alto, California: Stanford University Press, 1957.

MARY A. MEYER

1/83 Los Alamos, New Mexico

THE AUTHOR COMMENTS: Mary Meyer's comments about the process of discounting external occurrences that cause us mental confusion are very appropriate. William Perry of Harvard University has described the retreat from ambiguity that is common for college students in his book, *Forms*

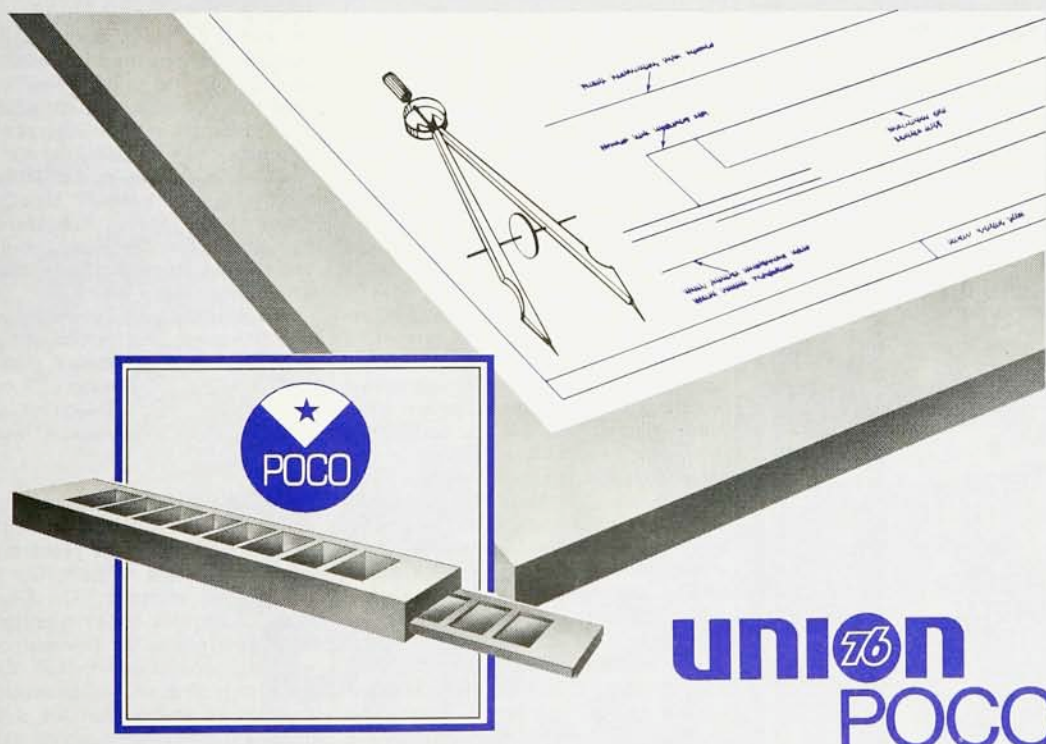
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letters

of Intellectual and Ethical Development in the College Years: A Scheme (Holt, Rinehart, and Winston, New York, 1970).

I share with Meyer the hope that the awareness of our own cognitive processes will enable us to be more effective scientists and teachers. This does raise two questions for me: To what degree can I as a researcher or teacher require others to confront, rather than retreat from, disequilibrating experiences? How can I model for others creative ways to handle cognitive dissonance?

ROBERT G. FULLER

University of Nebraska
Lincoln, Nebraska

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More on nuclear freeze

Every problem has one correct solution and a large number of approximations and erroneous attempts. The correct solution is not necessarily the simplest or the hardest; but at times it requires a fresh approach, different from the classical and the traditional. This is not uncommon in science, and scientists should not be tied to the traditional in discussing international problems. I am referring to the debate, "Freeze on Nuclear-Weapons..." in January (page 36).

The correct solution to excessive armaments, regardless of their nature, is complete disarmament; and that should cover all kinds of weapons down to bows and arrows, swords and clubs. Equipment whose function is to kill and destroy serves no good purpose and need not be manufactured, used or stored.

International conflicts should be resolved peacefully; involved parties, if unable to reach an agreement, should accept arbitration. The international community could exert enough pressure on involved nations until they comply. We have been moving in this direction, but not fast enough.

It is naive to think that such measures are simple and could be accomplished in a decade or two; but it is absurd to think they are impossible.

The basic requirements for such a momentous goal is a change in the mentality and stature of the world elites, political leaders and statesmen.

The notion that self-preservation requires one to fight for his family, his tribe, his city or his country does not stand to logic or reason.

Any form of self-preservation is meaningless unless it encompasses humanity as a whole.

Aside from the all-important human suffering and loss of human life, modern wars are extremely expensive in

economic terms and no nation has the right to waste our planet's resources on such absurd activities.

Scientists should shoulder the responsibility of pointing that out and should use all possible means to make it known to all; we can ill afford approximations and half-measures.

S. I. SALEM

California State University
Long Beach, California

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It was fun to read the nuclear freeze articles by my friends (and colleagues) Feiveson and von Hippel; and by my colleague (and friend) Lewis. The former present a factual and reasoned argument for a freeze and some creative suggestions for making it work; Lewis wrote his article as though for PHYSICS TODAY's first joke issue.

Midway through his article, Lewis confesses that he is neither for nor against the freeze. Later, he proposes non-nuclear defense of a subset of Minuteman silos, but then refers the reader to his first paragraph which says "to every complex problem there exists a solution that is simple, appealing and wrong."

Lewis raises puzzling questions when he applauds the bombing of the Iraqi reactor. Should Syria bomb the Israeli reactor at Dimona? Should Argentina go after the Brazilian reactors? What does he have in mind when he urges that the US "put... more effort into controlling the proliferation of nuclear weapons... by encouraging and participating in the international development of nuclear power"? He expresses dismay that some Americans like neither nuclear weapons nor nuclear power—but there is a connection and he knows it very well.

While there may be a case against the freeze, it was not made in the February issue of PHYSICS TODAY.

ROBERT C. AXTMANN

Princeton University
Princeton, New Jersey

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In equating the nuclear freeze with giving Laetrile to cancer patients—not helpful for solving the problem—Harold Lewis seems to be guilty of not reading his journals. The December issue of PHYSICS TODAY highlights an excellent reason for freezing nuclear weapons production—that is, the very dangerous and, so far, unmanageable radioactive wastes that are a by-product of the nuclear-weapons industry. I know that we normally think of the nuclear-power industry when discussing the problems of radioactive-waste disposal. I suspect, however, that the nuclear-weapons industry has to date furnished us and our grandchildren with a large majority of the radioactive