

doing so he may focus on one factor at a time or on several factors simultaneously.

How does a child move from concrete to formal operations? In general, the child becomes more and more proficient in organizing and structuring data. He becomes more capable of recognizing the need for a device that will yield a complete and logically exhaustive solution. He comes to understand that his concrete operational methods produce gaps, uncertainties, and contradictions. Consequently, he gropes for new methods of attack.

One of the most critical domains in which it is possible for the teacher to determine what stage of operations a student has achieved is the student's ability to isolate variables. At the lowest level of formal operations the student will form only a few of the total number of combinations: several binaries, some of the tertiaries, and a few quaternaries. At the highest level the student will be able to think in terms of *all* the possible combinations of the elements necessary to arrive at a determination of causal structure. In addition, he will have a systematic and orderly method of generating these combinations. His language will be filled with "if . . . then" terms, which indicate a hypotheticodeductive attitude toward the data.

From the above it is apparent that, for Piaget, formal thought consists not in specific behavior but in a generalized orientation toward problem-solving, organizing data, isolating and controlling variables, forming hypotheses, and finding logical justification and proof. The adolescent, then, is capable of ordering and patterning data. In addition, he can and does permit his imagination to soar—but in a controlled and planned way, which is solidly grounded in careful analysis and painstaking attention to detail.

Many of Piaget's insights into the world of the adolescent are necessarily tinged with European cultural attitudes, but some of his observations can be extrapolated to the United States. Piaget feels that the child and the adolescent are both dealing with the present, the here-and-now; but—and this is important—the adolescent can and does extend his conceptual range to the future, to the hypothetic, and to the spatially remote. The adolescent facing the future and his adult role in it goes through a phase in which he attributes almost unlimited power to his own thoughts. This is a time of dreaming of a glorious future. This is a time of dreaming of transforming the world through ideas—particularly through the student's own ideas.

For the adolescent this is a time to consider reasonably the problems of his environment. He is very much aware of such problems as pollution, overpopulation, and drugs. He can investigate many more ramifications of each of these problems. The simplistic attitude of "don't litter" has, for him, been transformed into the challenge to rebuild—to restructure the forces at work in his world.

The implications of Piaget's theory of the development of cognition should be obvious to teachers of secondary-school science. Do we provide our stu-

dents with learning experiences that befit their capacity for formal operations?

Note.—This paper was presented at the NABT 1972 national convention.

Suggested readings

- FLAVELL, J. H. 1968. *The developmental psychology of Jean Piaget*. Van Nostrand Co., Princeton, N.J.
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- _____. 1969. *The mechanisms of perception*. Basic Books, New York.
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THE FACTS OF LIFE

The student sneers, then boldly snaps: "You don't believe in God!"

Professor Wilkins smarts, then boldly smirks: "But I was just talking about glycolysis."

Student: "See, that proves it. I'll bet you don't even believe in treeness or the humors."

"Uh?"

"And I'll bet you think that love is biochemical."

"But . . ."

"Did you read *Origin of Species*? I mean really read it?"

"Seven times."

"And I'll bet you think that men and women are different."

"But the hypothalamus has this center of maternal . . ."

"The what?"

"I talked about that last week. The hypothalamus. You see, in the brain, just above your pituitary gland, there's . . ."

"Where's the soul?"

"Uh? I thought we were talking about the hypothalamus."

"Where's the soul?"

"Well, you see, there's this rock group playing at the gym tonight, and . . ."

"Not that kind. Sir, please don't get smart with me."

"I wish you'd get smart with me. Your grades could stand it."

"Is the soul biological? Is there a soul? And did we come from monkeys? And I'll bet you think that we can count and measure everything, too. Did you know that Dr. Howard's philosophy text says that nothing is real? Furthermore, I'll bet you believe in the universe."

"Now listen, Judy . . ."

"I'm Mike."

"Mike. I'm a biologist. And a scientist, I guess. I teach things about guts and brains and germs and pine-tree life cycles. I have an aquarium, I eat low-fat foods, and I like sexy movies—they keep the hormones fresh. But a philosopher I'm not. I have my own beliefs, but I'll be damned if I'm going to talk about them when my lesson plan says 'now draw structure of ATP—better use notes.' Ask Howard if he knows what's ATP. I'll bet he'll ask you if you mean objectively or subjectively. Get it? I'm a biologist. I teach facts and correct papers. Ask Howard to show you treeness."

"Do you believe in abortion?"

"Under what circumstances?"

"Do you believe in abortion, yes or no? Furthermore, do you believe in the appendix?"

"What do you mean do I believe in the appendix?"

"Was Einstein an atheist?"

"Mike, shut up. How many classes did you cut this semester?"

"I took the exam."

"Why?"

"Sir, did you know that California is going to force you to teach creationism and equate it to evolution?"

"Why? Are they different?"

"Some people say."

"I'll bet they don't know what's ATP. Or for that matter mutations, trilobites, continental drift, or the red shift."

"Uh?"

"Mike, listen. Next time you're in Howard's class, or in Harry's soshe class, tell them to first get some facts. Tell 'em to read Dobzhansky and Montagu; tell 'em that I'm not a dirty old man trying to destroy any religion, or treeness, or democracy, or Santa Claus. I'm just teaching you what's a tree, a stomach, or a gene, O.K.?"

"Facts are relative."

"Prove it."

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SHELTER MINIMIZES ERRORS IN OUTDOOR THERMOMETER READINGS

Most long-term ecologic studies require the measurement of daily maximum and minimum temperatures. These readings usually are considered accurate if the instruments are working properly. However, slight differences in the environment in which each thermometer is placed can lead to discrepancies of 15 °F or more.

To test this matter I devised an experiment with maximum–minimum thermometers (Fahrenheit scale). One was placed in a commercially produced instrument-shelter; the other was placed in

an open styrene-foam shipping container. The shipping container was placed on the ground within 2 m of the instrument shelter. The thermometer in the styrene-foam carton was therefore insulated from ground radiation and free to radiate its own heat to the open air.

When the experiment was begun, at 1700 hours, both thermometers indicated an air temperature of 60 °F. At 1915 the thermometer in the shelter read 51 °F, and the one in the styrene-foam box read 38 °F. The following morning the thermometer in the shelter stood at an overnight minimum of 40 °F and the one in the styrene-box stood at the overnight minimum of 28 °F.

I made similar observations while making an ecologic study of Alum Rock Canyon, near San Jose, Calif. A comparison of air-temperature readings between the north- and south-facing slopes over several months had to be made. Inconsistent readings were



Shelter for maximum–minimum thermometer.

noted when two maximum–minimum thermometers were left side by side—one lying on leaves, the other on bare ground. A difference of 15 °F between minimum readings was noted. This prompted further investigation into the cause.

I found that heat radiated from the earth at night was being inhibited by the leaves. Thus, the minimum readings of thermometers lying on leaf cover were much lower than the readings of thermometers lying on bare ground. I also noted that on foggy or cloudy nights the readings showed very little difference, regardless of the surface on which the thermometers were lying. However, if the night was clear the readings were inconsistent.

To standardize the method of reading the air temperature I experimented with field thermometer-shelters. Tests showed that the readings made in one of the shelters compared closely with those made inside commercial weather-station shelters.

The shelter shown in the figure is the best of my experimental designs. It consists of two styrene-foam disks 60 cm in diameter, separated by three wooden pegs. The thermometer itself is set off the bottom