01 Jan 1975

A Piagetian Approach To General Chemistry

Donald W. Beistel
Missouri University of Science and Technology

Recommended Citation
D. W. Beistel, "A Piagetian Approach To General Chemistry," *Journal of Chemical Education*, vol. 52, no. 3, pp. 151 - 152, American Chemical Society, Jan 1975.
The definitive version is available at https://doi.org/10.1021/ed052p151

D. W. Beistel
University of Missouri—Rolla
Rolla, 65401

A Piagetian Approach to General Chemistry

Psychologists have been aware of the stages of intellectual development for some time. Piaget's work, as available in English translation *(1, 2)*, categorized the development of intelligence from birth through age 15 into three major stages: (1) a sensorimotor period from birth to age two; (2) a concrete operations period from ages two to 11; and (3) the commencement of formal operations in the age range from 11–15. Although the age ranges are approximate the same sequence of development occurs in every child. Stages two and three are of great importance to chemistry teachers because stage two children are found in abundance at the freshman level in college *(3, 4)*. Those students have crossed the thresholds of high school science and mathematics without learning to conceptualize and theorize, the skills of a formal operational child. Instead they deal with concrete reality of a problem and make only limited extrapolations from it *(5)*. They deal with the "content of the problem rather than the form of relations within it."

If a stage two child is asked to deduce Archimedes' principle on giving him a bucket of water and several objects of varying size and weight, he might conclude that objects of stone will sink "because they are stone" or that wood floats "because there is air inside." But he will not reduce the problem to one of comparing the weights of equal volumes of water and an object unless told to do so. Further, if given the formula for density he will not deduce the requirement that $(w_{\text{object}}/V_{\text{object}}) < 1$ if the object is to float. If he were able to deduce the relation he would be operating on the operations, the first step toward formal thought.

We have all seen students who dutifully perform "cookbook" experiments in the laboratory. They take data, fill the blanks in a prepared form, and then leave the laboratory confused and frustrated. At the introductory level the confused and frustrated student may be concrete operational or operating on operations. If he is concrete operational the instructor may have failed to help him toward formal thought through a progressive question-answer session during which the student is led to the relationship and its general application. If he is at the stage of operating on operations, he may have been led too quickly in his training to the Archimedes' experiment. In either case the instructor has failed to grasp and apply Piaget theory to his course.

The concrete student can become formal by careful experimentation and critique as Renner *(4)* and Karplus *(6)* have reported. The key to the transformation is an extensive critique during which the student deduces the principle. If the flowsheet for the experiment is a typical, fill-in-the-blank form *(7, 8)* however, the student flounders down his concrete path. A performance test of one or two questions would indicate only that the student had found answers to those questions during the laboratory period. It would not necessarily test his knowledge of the theory underlying his experimental studies, nor would it distinguish between lack of motivation and stage of intellectual development for cases where no learning occurred.

The student advanced enough to be operating on operations would grow toward formal operational thought through a "cookbook approach" if the experiment developed with optimal discrepancy. The Archimedes' experiment can be formed in a manner that develops a chain of new knowledge of sufficient association to prior learning that it can be assimilated. The order of testing the objects is critical here and so is the link between the Archimedes' experiment and previous experimentation. That is, weight and volume measurements on the objects must be demonstrated prior to the current experiment. Only then can the student amend his cognitive structure to accept the new inputs and build hypotheses from them. Finally, even the pre-formal operational student must be tested thoroughly at the conclusion of the experiment if he is to progress in intellectual development during the laboratory period.

One should conclude from the above that when teaching principles in the laboratory, we can aid a student in his intellectual growth and that his intellectual growth may be one of our ultimate accomplishments as teachers of science. The student cannot hope to grasp formal concepts such as acidity or electrochemical potential unless he is formal operational. Neither can he consider the tetrahedra and octahedra of molecular structure unless he can visualize without the aid of models. I submit that when a student fails or drops an introductory, laboratory course such as general chemistry the fault may lie in our haste to process him toward higher, "more interesting" topics (and not because "he was lazy" or "had a poor background in mathematics").

We err in both our cookbook laboratories and the ordering of topics in our lectures. Typical freshman texts such as Rochow *(9)*, Sienko and Plane *(10)* and Dillard *(11)* begin with atomic structure, reviews of basic mathematics, and similar, formal concepts. The concrete operational student is thrust far beyond his intellectual level from the beginning of the first semester. Unrelated laboratory experiments in qualitative or quantitative analysis add to his predicament and he either drops quickly or fails.

If the course had begun with the gas laws, he could cope with lecture and laboratory in concrete terms. He could then progress to other bulk properties such as solution theory (vapor pressure relationships and other colligative properties) before proceeding to the microscopic level and onward. A suggested list of topics is shown in the table. It recognizes that not all entering freshmen are formal operational and helps the concrete operational student become formal under the guise of "review." It is not the final solution to the problem of selecting topics for a first semester of general chemistry, but could be a constructive step toward the solution.

We made the initial step years ago when we reduced the general content of beginning chemistry to the mole concept. General chemistry gives many applications of the mole concept, so much so that one can unify the course for the typical freshman by pointing out that fact from time to time. According to Piaget if one revisits a concept

Presented to the Third Biennial ACS Conference on Chemical Education, Pennsylvania State University, July 1974.

Syllabus for the First Semester of General Chemistry, Optimized to Stimulate Intellectual Development

Lecture Topics	Laboratory
Gases—Boyle's and Charles' laws, ideal gas equation, Dalton's law, van der Waal's equation and real gases (no kinetic theory here)	Boyles law, compressibility of a gas, molecular weights of gases
Solutions—vapor pressure, boiling point elevation-freezing point depression, osmosis, electrolytes (no structure at this time)	Boiling points—pure solvents, dilute solutions of molecular species and electrolytes
Changes of state—phase equilibria for one and two component systems, the concept of dynamic equilibrium	Derivation of the phase rule
Thermodynamics—heats of fusion and vaporization, heat capacity, internal energy and work, Hess's law, free energy	Heat of vaporization—derivation of Trouton's rule
Equilibrium—equilibrium constants and their interrelationships, gaseous equilibria, acid-base equilibria, solubilities	*p*H of weak acids (derivation of an acidity scale), *p*H of salts

from many routes, recognizing the need to maintain optimum discrepancy if learning is to occur, he will obtain maximum benefit from his efforts.

Further, one can stimulate intellectual development in lecture by applying the Piagetian techniques of Karplus *(6)*. Those include the introduction of new topics in concrete terms, the occasional unsatisfactory hypothesis or incorrect conclusion that is provided for student evaluation, the creation of discrepant events, the description of reversibility for a process or concept, and so on. One does not appear foolish to the student audience as he blunders through a fallacious argument if the student expects an occasional deception. In fact, the superior (formal) student thrives on the opportunities it affords.

The selective, liberal arts college need show little concern for a Piaget approach unless it accepts a percentage of minority students in the freshman class, as some do. Care in text selection is more appropriate for the public college and university, required by law to admit marginal students and thankful for their numbers in many cases. The list of freshman on probation might be reduced at those institutions if instructors were cognizant of Piaget's studies of some 40 years ago. Perhaps the annual Proceedings of the Jean Piaget Society should be required reading for authors of texts on general chemistry as well as for psychologists and physical science teachers such as Renner and Karplus.

Acknowledgment

I wish to thank the members of the Committee on Intellectual Development, College of Arts and Sciences, the University of Missouri—Rolla for many stimulating discussions. Special thanks are due to Professors H. Q. Fuller and William Murphy of UMR for source materials and valuable criticisms of the Piaget theory.

Literature Cited

(1) Piaget, Jean, and Szeminska, Alina, "The Child's Conception of Number," (*Translators:* Gattegno, C., and Hodgson, F. M.) Humanities Press, New York, 1952.

(2) Piaget, Jean, "The Origins of Intelligence in Children," (*Translator:* Cook, M.,) International Universities Press, New York, 1952.

(3) Karplus, R., *Sch. Sci. and Math.*, **70**, 813 (1970).

(4) Renner, J. W., and Lawson, A. E., *Phys. Teach.*, **11**, 165 (1973).

(5) Phillips, J. L., Jr., "The Origins of Intellect. Piaget's Theory," W. H. Freeman and Co., New York, 1969, p. 104.

(6) Karplus, R., "Opportunities for Concrete and Formal Thinking on Science Tasks," presentation to the 3rd annual meeting of the Jean Piaget Society, May 22, 1973.

(7) Frantz, H. W., and Mahon, L. E., "Chemical Principles in the Laboratory," W. H. Freeman and Co., San Francisco, 1966, 1970.

(8) Day, R. A., and Johnson, R. C., "Laboratory Manual General Chemistry," Prentice-Hall, Inc., Englewood Cliffs, N. J., 1974.

(9) Rochow, E. G., Fleck, G., and Blackburn, T. R., "Chemistry Molecules that Matter," Holt, Rinehart and Winston, Inc., New York, 1974.

(10) Sienko, M. J., and Plane, R. A., "Chemistry," 3rd Ed., McGraw-Hill Book Co., New York, 1966.

(11) Dillard, C. R., and Goldberg, D. E., "Chemistry," The Macmillan Co., New York, 1971.