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ABSTRACT

Piaget's developmental theory is discussed and several research findings that involve Piaget's theories are reported. The understanding of reasoning patterns is presented as a means for the science teacher to identify the conceptual emphasis and demands of the subject matter and to help students develop more advanced reasoning patterns than they use currently. (MLH)

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SCIENCE TEACHING AND THE DEVELOPMENT OF REASONING

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and
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Editors

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SCIENCE TEACHING AND THE DEVELOPMENT OF REASONING

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In your interactions with secondary school students learning science you have probably become aware of large differences in student ability to understand science concepts, conduct investigations, and/or solve specific problems. Some students are extremely capable, while others demonstrate peculiar and inappropriate reasoning strategies. Sometimes, even after your best efforts, they seem unable to grasp ideas that to you are eminently clear. Often students are able to follow problem solutions but are at a loss when required to transfer those strategies to slightly different problems. You wonder why students are able to respond successfully to examination questions and then after one month or so forget almost all of what they learned.

I believe that teachers' understanding of these situations and of student differences can be significantly aided by the developmental theory of Jean Piaget. For several years, my colleagues Warren Wollman and Anton Lawson and I have investigated the relation of this theory to science teaching at the secondary school level. Other researchers with whom we have been in touch and whose work has influenced our thinking include Arnold Arons (University of Washington, Seattle), Kenneth Lovell (Leeds, England), Eric Lunzer (Nottingham, England), John W. Renner (Norman, Oklahoma), Michael Shayer (London), and Antonio Suarez (Zurich, Switzerland).

In addition to researching students' reasoning, we have been concerned with communicating the important features of Piaget's theory to secondary school teachers, so that they might apply it in their classrooms and provide larger field tests of its applicability than our small research group could undertake. In my presentation here I shall describe our interpretation of Piaget's theory in the light of recent findings applicable to adolescents.

Piaget's Theory and Reasoning Patterns

Piaget has characterized human intellectual development in terms of four stages.[1] The first two, called sensory-motor and pre-operational, are usually completed when a child is seven or eight years old. Following these are two stages of logical operations, called concrete thought and formal thought, which are relevant to secondary school students. I shall give details below.

Piaget has ascribed the process whereby individuals advance from one stage to the next to four contributing factors: maturation, experience with the physical environment, social transmission, and "equilibration." The last item, "equilibration," designates an internal mental process in which new experiences are combined with prior expectations and generate new logical operations.

To make the stage concept useful, one has to describe the reasoning of an individual whose development has reached each of the stages. This description has been stated by Piaget in terms of the mental operations the individual uses when facing certain problems. To avoid confusion with other uses of the term "operation" in science, I prefer to employ the phrase "reasoning patterns." Two examples of behavior based on reasoning patterns are (1) serial ordering a set of sticks according to their length and (2) investigating the effect of fertilizer on clover by setting up several test plantings that are treated alike in all respects except in the amount of fertilizer applied to them.

From the research of Piaget and others, certain rules have been formulated for identifying reasoning patterns as belonging to concrete or to formal thought. In general, reasoning that makes use of direct experience, concrete objects, and familiar actions is classified as a concrete reasoning pattern, such as (1) above. Reasoning that is based on abstractions and that transcends experience is classified as a formal reasoning pattern, such as (2) above. Here is a more extensive list of clues that are helpful in classifying reasoning patterns.[2]

When using concrete reasoning patterns, the individual:

C1 Applies classifications and generalizations based on observable criteria (e.g., consistently distinguishes between acids and bases according to the color of litmus paper; all dogs are animals, but not all animals are dogs).

C2 Applies conservation logic--a quantity remains the same if nothing is added or taken away, two equal quantities give equal results if they are subjected to equal changes (e.g., when all the water in a beaker is poured into an empty graduated cylinder, the amount originally in the beaker is equal to the amount ultimately in the cylinder).

C3 Applies serial ordering and establishes a one-to-one correspondence between two observable sets (e.g., small animals have a fast heart beat while large animals have a slow heart beat).

By using these patterns, the individual can reason and solve problems beyond his ability in the preoperational stage. Yet there are many limitations if concrete reasoning patterns are compared to formal ones.

When using formal reasoning patterns, the individual:

F1 Applies multiple classification, conservation logic, serial ordering, and other reasoning patterns to concepts, abstract properties, axioms, and theories (e.g., distinguishes between oxidation and reduction reactions, uses the energy conservation principle, arranges lower and higher plants in an evolutionary sequence, makes inferences from the theory according to which the earth's crust consists of rigid plates).

F2 Applies combinatorial reasoning, considering all conceivable combinations (e.g., systematically enumerates the genotypes and phenotypes with respect to characteristics governed by two or more genes).

F3 States and interprets functional relationships in mathematical form (e.g., the rate of diffusion of a molecule through a semi-permeable membrane is inversely proportional to the square root of its molecular weight).

F4 Recognizes the necessity of an experimental design that controls all variables but the one being investigated (e.g., sets up the clover experiment mentioned above).

F5 Reflects upon his own reasoning to look for inconsistencies or contradictions with other known information.

In the following table, the most important differences between concrete and formal reasoning patterns are summarized:

TABLE 1. CONCRETE AND FORMAL REASONING PATTERNS

	CONCRETE	FORMAL
(a)	Needs reference to familiar actions, objects, and observable properties.	Can reason with concepts, relationships, abstract properties, axioms, and theories; uses symbols to express ideas.
(b)	Uses reasoning patterns C1 - C3, but not patterns F1 - F5.	Uses reasoning patterns F1 - F5 as well as C1 - C3.
(c)	Needs step-by-step instructions in a lengthy procedure.	Can plan a lengthy procedure given certain overall goals and resources.
(d)	Is not aware of his own reasoning, inconsistencies among various statements he makes, or contradictions with other known facts.	Is aware and critical of his own reasoning; actively seeks checks on the validity of his conclusions by appealing to other known information.

Present Status of the Theory of Formal Thought

While each of the two lists in the previous section has a certain theme, my enumeration of formal reasoning patterns does not communicate the unity originally proposed by Piaget. Piaget conceived of formal reasoning patterns as dealing with logical propositions and having the organizational structure of an algebraic group called the INRC group. I will omit details because recent workers have not found evidence to support Piaget's proposals in these respects. Neimark[3] has summarized the present status by concluding that there is more advanced intellectual functioning than concrete thought, but that such reasoning is not used as reliably and universally as Piaget's writings imply. Lunzer has expressed similar views.[4] In fact, Piaget has adopted a more flexible position in the last few years.[5]

To give you one example of a study that leads to difficulty for the highly unified view of formal thought, I refer to unpublished data collected in a survey of student reasoning in seven countries carried out in 1974.[6] My collaborators and I presented several thousand eighth and ninth grade students with a task in proportional reasoning and a second task requiring control of variables (reasoning patterns F3 and F4). We found that United States students succeeded more frequently on control of variables, while Austrian students succeeded more frequently on proportional reasoning. For British students, performance on the two tasks was more closely similar than for either of the other two samples mentioned. Using the British results as a guide, one might claim that the two tasks are about equally difficult. The lack of correspondence in Austria and the United States can then not be explained by asserting that eighth graders in one of these countries are more or less advanced toward formal thought than students in the other. We concluded that there were differential effects of instruction that did not generalize directly from one formal reasoning pattern to another.

In spite of the fact that the unity of formal reasoning patterns appears to be elusive, some research studies suggest strongly that there is a bond relating them. Consider, for instance, the factor structure of ten Piagetian tasks reported by Lawson and Nordland[7] after interviewing ninety-six seventh graders in an urban school. They identified two principal components that accounted for fifty-five percent of the variance in their data. Four tasks--equilibrium in the balance, separation of variables, conservation of displaced volume (both cylinders and clay)--loaded primarily on the first component. Three other tasks (conservation of number, solid amount, and liquid amount) loaded exclusively on the second component. The last three tasks (conservation of length, area, and weight) loaded on both components. The authors concluded that the first and second components represent formal and concrete thought more comprehensively than these are represented in any single reasoning pattern. Perhaps, then, there is a unity after all!

One shortcoming of the Lawson-Nordland study is its emphasis on conservation tasks. Lawson is now planning a more comprehensive investigation that includes a wider variety of reasoning patterns.

Applications to Science Teaching

The science teacher who is interested in applying Piaget's theory can benefit but must be cautious to avoid the difficulties with the theory that are even more prominent in a classroom than they are during a research study. I, therefore, urge teachers to concentrate on identifying their students' reasoning patterns and not to expect that each student's entire behavior can be classified neatly as reflecting either concrete or formal thought. Most important is the teacher's willingness to accept the fact, documented in recent studies, that a large fraction of students will use concrete reasoning patterns extensively.[6,8,9]

By becoming aware of reasoning patterns needed to understand a particular science course, a teacher can (1) identify the conceptual emphasis and demands of the subject matter and (2) help students develop more advanced reasoning patterns than they use currently. I shall now elaborate on item 1 and then devote the next section of this article to item 2.

Here are nine concepts that are usually included in secondary school science courses: density, temperature, cell, gene, environment, chemical bond, periodic system of elements, acid-base, and ideal gas. What reasoning patterns must a student use to understand these?[10]

Let us first look at density. Density must be understood in terms of other concepts--mass and volume-- rather than in terms of direct experience. Furthermore, the ratio relationship must be applied to mass and volume. Both of these mental steps make use of formal reasoning patterns, items F1 and F3 in my earlier list. For this reason, density may be called a "formal" concept.

Temperature can be defined in terms of sensations (warm/cold) or thermometer readings. When this is done, temperature may be called a "concrete" concept, because it is based on observable criteria and thus requires concrete reasoning patterns (item C1 in my list) for understanding. Temperature, however, can also be defined as a measure of the average molecular kinetic energy. If this is done, temperature becomes a "formal" concept whose understanding derives from other concepts (molecule, kinetic energy), the kinetic-molecular theory, and mathematical relationships (items F1 and F3).

This example illustrates that a concept with several meanings may be either "concrete" or "formal," depending on the meaning used. To identify the reasoning required of the students in a course, the teacher must be clear about the meaning of the concepts that are introduced. Special care must be taken to use a concept always with the meaning that was explained to the students, and not to expect that the introduction of temperature or another concept as "concrete" concept can be extended automatically to an application of the concept's "formal" significance.

Now I shall briefly comment on the other concepts I have listed above. It seems to me that all of them can be defined as "formal" concepts, but that cell, environment, and acid-base can also be given definitions as "concrete" concepts in terms of familiar actions and examples. The cell can be observed when tissue is examined through a microscope; the environment and environmental factors such as heat, moisture, and light can be observed easily; and acid-base can be distinguished by the use of a chemical indicator, interaction with washing soda, or--in safe cases--by tasting.

The remaining concepts--gene, chemical bond, periodic system, and ideal gas--all require formal reasoning patterns for their understanding. They can only be defined in terms of other concepts, abstract properties, theories, and mathematical relationships. I see no way of defining them as "concrete" concepts.

The Formation of Reasoning Patterns by Self-Regulation

At the beginning of this article, I enumerated problems that a secondary school science teacher is likely to encounter. In my discussion, I have indicated that some of the problems can be ascribed to the fact that many students use concrete reasoning patterns, yet that the subject matter often requires formal thought. Unless science courses are to become highly selective and admit only students who use formal reasoning patterns with ease, I strongly recommend that the formation of formal reasoning patterns be made an important course objective, as important as the covering of a certain body of subject matter.

Let us, therefore, return to the process of intellectual development. Rather than using Piaget's term "equilibration" for the essential but hard-to-define fourth contribution, I prefer the term "self-regulation," which has fewer science connotations and emphasizes the active role played by the individual.

The key to the formation of new reasoning patterns is an individuals' responding to his or her inadequacy in using the present reasoning patterns to cope with a demand. An analogy in physical actions is your response to driving an unfamiliar car with a brake of different stiffness from that in your car. You first use your accustomed foot pressure, discover that it is unsatisfactory, and then try variations until the car responds smoothly. Your first encounter with an unsuspected power brake can lead to near-disaster!

A child using a concrete reasoning pattern in a pizza parlor may decide that the eight-inch pizza costing $1.25 is too small and may order a sixteen-inch size without looking at the price, in expectation that is costs $2.50, "Because it's twice as big." Imagine the dismay when the giant pizza arrives, together with a check for about $5.--! Here is a surprise that may trigger the search for a more successful reasoning pattern to cope with the pizza size/price problem, a mathematical relationship requiring a formal reasoning pattern.

My colleagues have been gathering evidence[12,13,14] that the learning cycle, which was introduced as part of the Science Curriculum Improvement Study[15] to facilitate concept development at the elementary school level, is also effective with older students and the introduction of formal concepts.[16] The learning cycle consists of three instructional phases that combine experience, serial transmission and encourage self-regulation.[17] For our purposes here I shall call the three phases exploration, concept introduction, and concept application.

During exploration, the students gain experience with the environment--they learn through their own actions and reactions in a new situation. In this phase they explore new materials and new ideas with minimal guidance or expectation of specific accomplishments. The new experience should raise questions or complexities that they cannot resolve with their accustomed patterns of reasoning, as in the pizza example. As a result, mental disequilibrium will occur and the students will be ready for self-regulation.

The second phase, concept introduction, provides social transmission--it starts with the definition of a new concept or principle that helps the students apply a new pattern of reasoning to their experiences. In the pizza problem, the relation of area to diameter would be the key idea, but might be first illustrated by means of the area and side of a square rather than a circle. The concept may be introduced by the teacher, a textbook, a film, or another medium. This step, which aids self-regulation, should always follow exploration and relate to the exploration activities.

Concept introduction is especially effective when it involves the formal definition of a concept whose concrete definition is already understood by the students. Since, for instance, a square can easily be subdivided into unit squares, determining the area of a square need only make use of concrete reasoning patterns. This illustration, as I suggested, would help lead the students toward conceptualizing and approximating the area of a circle, a step that requires a formal reasoning pattern because a circle cannot be subdivided completely into unit squares by a finite number of steps.

In the last phase of the learning cycle, concept application, familiarization takes place as students apply the new concept and/or reasoning pattern to additional situations. In the pizza area example, a valuable application activity might involve the construction of sets of similar rectangles, ellipses, and other figures out of cardboard and investigating the relationship of their diameter to their weight. In this phase, physical experience with materials and social interactions with teacher and peers play a role.

Concept application is necessary to extend the range of applicability of the new concept. This phase provides additional time and experiences for self-regulation. Furthermore, concept application activities aid the students whose conceptual reorganization takes place more slowly than average or who did not adequately relate the teacher's original explanation to their experiences. Individual conferences with these students to identify and resolve their difficulties are especially valuable.

Conclusion

In this brief presentation I have only been able to make a very simplified introduction to a complicated area of research that holds a great deal of promise for the improvement of secondary science teaching. It is most important that Piaget's ideas can and should be used actively for instructional improvement, and should not be interpreted as implying that education must wait until development has occurred spontaneously. Piaget[18] has described the interaction of education and development in these words: "Thus education is. . . a necessary formative condition toward natural development itself." Of course, the theory will not solve all educational problems, but it can help in those aspects of concept development and understanding which make science courses especially difficult for many students.

I am indebted to Anton E. Lawson for critical comments and helpful suggestions in the preparation of this presentation.

References

1. B. Inhelder and J. Piaget. The Growth of Logical Thinking from Childhood to Adolescence. New York: Basic Books, 1958.

2. Adapted from R. Karplus, A. E. Lawson, W. T. Wollman, M. Appel, R. Bernoff, A. Howe, J. J. Rusch, and F. Sullivan. "Workshop on Science Teaching and the Development of Reasoning." Berkeley, California: Lawrence Hall of Science, 1976, Module 2. Arrangements for the distribution of the workshop materials are being made.

3. Edith D. Neimark. "Intellectual Development During Adolescence." In Review of Child Development Research, Volume 4, edited by Frances Degen Horwitz. Chicago: The University of Chicago Press, 1975.

4. Eric A. Lunzer. "Formal Reasoning: A Re-Appraisal." In Proceedings of the Third Annual Symposium of the Jean Piaget Society, Philadelphia: Temple University (in press).

5. Jean Piaget. "Intellectual Evolution from Adolescence to Adulthood." Human Development, 15: 1-12, 1972.

6. R. Karplus, E. F. Karplus, M. Formisano, and A. C. Paulsen. "Proportional Reasoning and Control of Variables in Seven Countries." Berkeley, California: Lawrence Hall of Science, 1975.

7. Anton E. Lawson and Floyd H. Nordland. "The Factor Structure of Some Piagetian Tasks." Journal of Research in Science Teaching (in press).

8. Warren T. Wollman. "Intellectual Development Beyond Elementary School VI: Controlling Variables: A Survey." Submitted to Journal of Experimental Child Psychology.

9. Robert Karplus and Rita W. Peterson. "Intellectual Development Beyond Elementary School II: Ratio, A Survey." School Science and Mathematics 1970 70(9), 813-820.

10. Adapted from Reference 2, Module 7.

11. Adapted from Reference 2, Module 5.

12. A. E. Lawson, A. J. D. Blake, and F. H. Nordland. "Training Effects and Generalization of the Ability to Control Variables in High School Biology Students." Science Education, 59(3) 387-396 (1975).

13. A. E. Lawson and W. T. Wollman. "Teaching Proportions and Intellectual Development." Journal for Research in Mathematics Education (submitted).

14. Anton E. Lawson and Warren T. Wollman. "Encouraging the Transition from Concrete to Formal Cognitive Functioning--An Experiment." Journal of Research in Science Teaching (in press).

15. Science Curriculum Improvement Study. Chicago: Rand McNally and Co., 1970-1974.

16. Substantially similar recommendations phrased in different terms have been made by H. A. Shoemacker, "The Functional Context of Instruction," Professional Paper 35-67, Human Resources Research Office, George Washington University, 1967; and T. G. Sticht, "Comments on Kenneth Lovell's Paper: Does Learning Recapitulate Ontogeny?" in D. R. Green, M. P. Ford, and G. B. Flamer (Eds.), Measurement and Piaget, New York: McGraw-Hill, 1971.

17. SCIS Teacher's Handbook. Berkeley, California: Lawrence Hall of Science, 1974, page 29. In the SCIS program, the three phases of the learning cycle are called exploration, invention, and discovery.

18. Jean Piaget. To Understand is to Invent. New York: Grossman Publishers, 1973, page 52.