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CHAPTER TWO

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by
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Since the fall of 1978, my colleague, Dr. Robert G. Fuller, and I have been involved in a project to document on videotape the variety of ways in which students approach problems. We chose problems that adequate solutions of which call for the use of certain sorts of reasoning strategies. Our materials were selected to afford rich ground for investigation by subjects of a range of operational abilities. We began by doing Piagetian clinical interviews of elementary school children and then of college students. We hope, eventually, to do similar interviews of junior high and senior high school students, too, and thus to assemble videotaped programs illustrating the development of reasoning strategies and some of the "pitfalls" and "diversions" that occur along the continuum of logical development. This paper presents some of the information we gained from the interviews of college students and discusses what it may mean for higher education in the 1980s.

The clinical interview situation through which our information on students' reasoning strategies was gotten is a vehicle developed by Piaget to get maximum access to the ways in which individuals construct their reality through the interaction of what they already know, believe, and to with what they are presented by new experiences. The interview format provides intensive experience on a problem or task for the subject in a one-to-one interaction with an interviewer whose primary aim is to come to understand what the subject thinks, why and how he/she arrived at those ideas.

A Piagetian interviewer is not so much interested in whether the subject gives one or another answer or solution to the problem as he/she is concerned to see by what strategies and for what sorts of reasons the subject has come to regard as sensible, appropriate, and true the solutions he/she has proposed. We presume that subjects will try to present answers/solutions that they regard as reasonable and called for or likely, given their view of the world. The interviewer attends to the methods the subjects use in reasoning out the problems and probes the subjects in ways that will reveal whether they are able to do the logical processing required to handle the problem adequately. Thus, when a subject presents a general statement about how the things in question work, it is of interest to the interviewer to get the subject to identify the sorts of situations that might yield a falsification of his/her general statement. Further, it is germaine to the interviewer's concern to find out how the subject responds in the face of such falsifying evidence -- will the general statement be entirely discarded and something quite different be brought in to fill its place, or will the negative information be used constructively in a testable revision of the general statement? We are also interested in how subjects handle problems the solutions of which they do not know or believe they do not know. In such situations the interview setting becomes an occasion for learning, for figuring out a means to a solution. Hence, memory of specific information that may be applicable is not so much tested as is the ability to create methods to arrive at solutions.

In all the interviews, elementary school and college level, subjects were given the Floating/Sinking Objects Task using materials and instructions much like those used by Inhelder and Piaget (1958, Chapter 2). Study of the behavior of our college subjects and our fifth and sixth graders on the same task yields some interesting comparisons. First the upper elementary schoolers generally explored \the objects more fully, interacted more with the materials in a "discovery" mood, created ways of expressing their ideas with only an occasional word or two of scientific jargon, relying on their ordinary language for their expressions. It was a task they had not been seriously asked to think about by an adult before, although they had, each of them, thought about the basic question -- "What makes some things float and others sink?" -- regarded it as an exceedingly interesting question. It was not regarded as a question the answer to which they ought already to have learned, and they revealed the beginnings of formal operations in their use of propositional reasoning, their responses to negative information (by revising hypotheses), their beginning to relate the aspects of weight and of size of the objects to broach a solution.

On the other hand, many of the college students came to the task assuming they ought to know "the answers" to our questions, trying to remember formulae and scientific terminology and trying to apply those to the specifics of our situation. Believing they should already know seemed to be a factor in the less adequately prepared subjects' not entering actively into manipulating the materials and the situation so they could discover a workable solution. When they tested their "theories" against the phenomenon of the situation, they sometimes were frustrated and perplexed by the negative evidence but did not readily question their hypotheses and systematically set out to isolate their difficulty and correct it. It was quite clear that, for all of them, the solution of the tasks lay in the aspects of weight and size of the objects. But still many of them did not regard volume or displacement in water as indications of size that are as relevant as surface area of the objects and/or the area of the objects' surface facing the water. Some brought in the terms of center of gravity, specific gravity, molecular weight, as well as density and surface tension, to deal with the problem. The college subjects focusing on the amount of surface facing the water made no distinction between the "size" of the object and the "size" of the materials of which it was made and, thus, had difficulty accounting for the fact that the jar lid often floats edges-up and not edges-down. Those focusing on the kinds of substances presented, expecting wood to float and rocks to sink, were visibly dismayed by a piece of rosewood that sinks and a chunk of pumice that floats, and shifted their emphasis to the relative weights of these objects-- "it's real heavy," and "it's very light" -- often without relating the weight to the size.

Of the thirteen college students interviewed, eight of whom had completed two year of college level science courses, only one approached the problem with a clear use of concepts of displacement in water and mass as well as a systematic means of employing the concepts in the investigation of the materials in question. That is not to say, however, that only one of our subjects revealed in the handling of the task an array of formal operations adequate to the situation. There was one other subject, who had not had formal college science courses, who employed the thorough systematic approach characteristic of formal operational thinking, but without the trappings of scientific terminology.

The procedures used by these two college subjects were different from the eleven other subjects on this task in the followings ways:

1) They sorted the objects into three classes at the outset -- floaters, sinkers, and those that can be made to float and sink -- other subjects who made three classes labeled the third, "objects I'm not sure about."

2) They operated readily with the concept of volume, applying it to the water as well as to the objects, without confusing it with surface area.

3) They employed a distinction between the density of an object and the density of the material of which the object is made. Thus, they were able to deal with the phenomenon of the flat sheet of foil sinking when pushed under the water, while, as a crumpled up ball of foil, it buoyed back up when pushed down.

4) They death systematically with the situation to eliminate the operation of surface tension of the water as a factor in the floating of some objects. Here the use of propositional reasoning is a powerful aid for the investigator. For example regarding the rubber band and, which he had had in his class of sinkers, and now, having put it in the water, finds it staying on top, Jack reasons: "Either it's not as dense as water or it's so light that it's not going to break the surface tension of the water. If it's surface tension that's keeping (the rubber band) up, then, if I poke it down under the water, it should not buoy back up to the surface." Pushing down the rubber band, it goes down to the bottom of the tub, he finds it is a sinker (more dense than water) and therefore must have been held atop the water at first by surface tension.

5) Their stated views and their behavior during the task made up an integrated whole--concepts were related with one another allowing attack on a given question from more than one direction, and the patterns of overt behavior and interaction with the objects were consistent with the verbalized general ideas, and the language expressions called into play were carefully used, honed tools which were aids to the reasoning, rather than masks behind which to hide reasoning while verbally "faking it."

Dealing with the task adequately should have led all the college students into applications of the concept of density in ways that required formal operational thinking. Density involves relating the mass of an object or material to its volume, thus the density of an object is the ratio of its mass to its volume. Whether an object floats or sinks must be answered by comparing the density of the object with the density of the substance in which it is to be placed. Hence, this task requires the use of formal operational structures which consider relations of relations. Aspects of some of the objects we used provide the occasions for intervening forces such as surface tension to enter, making the subject generate or adopt ways to distinguish between causes. Thus hypothetical-deductive thinking is required in this process.

Although our college subjects all displayed hypothetical-deductive structures to some degree and related different properties of the objects in some version of "density," most of them failed to show well developed and integrated formal thought. Thus, they clung to objects' surface area as of prime importance without considering what the relevant "surface area" of the water would be. Some clung to presenting definitions or formulae they neither properly understood (witness their behaviors during the interviews) nor felt confident enough about their own reasoning competences to permit their abandonment.

Many of the college subjects were also given the Equal-Arm Balance Task in their interviews. Modeled upon the task as described by Inhelder and Piaget (1958, Chapter 11), we made one change to make it a more interesting encounter for our young adults by using ordinary sticks for our balances. In order to see how the students would use numbers to make their predictions of weight placements, some subjects were given an ordinary meter stick on which they could see the numbers in ascending order from left to right in centimeters, while other subjects had a stick which contained no numbers, but only equally spaced holes marked by an array of colored stripes radiating outward from the center of the stick. Weights in all cases were carefully measured groups of washers bound together with wire and having a length of wire by which to hang them on the balance arms -- e.g., the 2-washer-pack together with its wires weighed twice the 1-washer-pack with its wire, etc..

The problems posed the subjects were of two types: 1) Given a certain weight-pack at a set distance out on one arm, where would you hang this weight-pack on the other arm to make it balance? and 2) Given a weight-pack at a certain place on one arm and a weight-pack at a certain place on other arm, can you hang this weight-pack somewhere on the latter arm so that it will be balanced? In each case, of course, subjects are asked to explain their reasoning--whether they've concluded that it cannot be done or that it can be achieved by a certain placement. Here, as in the Floating/Sinking task, it is the procedures used, the strategies offered by the subject that are important. If a subject makes calculation errors or reads the marks off the balance arm incorrectly, corrections are openly encouraged in the process of "being clear about what's being done."

Again, most of our college subjects came to this task having "learned a formula" somewhere and these attempted to retrieve it from memory and to apply it to the given weights on the arms. Among the successful, there were basically two strategies used: 1) the equal products strategy in which the weight times the distance from the fulcrum on one arm is taken to be equal to the weight times the distance from the fulcrum on the other arm; 2) the equal proportions strategy in which the weight on the left is to the weight on the right in the same proportion as the distance on the right is to the distance on the left. (Note: The last calls for an inverse proportion.) Given any three quantities, one can deduce the unknown by using sixth grade mathematics.

In dealing with the balance problem, we encountered again the same reticence about using the materials and apparatus at hand to find out how to solve the problems and/or to remind themselves of the formula they once "learned." And in one case, the subject (after several halting attempts at generating a proportional strategy) having finally recalled the equal products formula, did not readily apply it to the weights and distances in the problem at hand until the interviewer prodded him to try. On the other hand, there was one subject who claimed no prior knowledge of how to accomplish the task, but plunged in with an inquiring stance to explore the stick, as she moved the weights on one side in forming and testing her guesses until she was able to recognize an equal products relationship in the figures representing the weight-packs and distances from several problems in a row. (She had been marking the numbers on a scratchpad.)

The behavior of the six subjects who used the unnumbered stick proved interesting. One worked entirely on an intuitive basis, imposing no numbers at all on the situation. When the subject moved the weights, having predicted a placement incorrectly, it was by "chunks" -- first two or three holes/stripes to the left, then several to the right -- responding unsystematically. One subject believed that, given unequal weights, there was no way they could be placed on teh arms so as to balance one another "because no matter where they are, gravity will pull the same on both of them and the arm with the heavier weight will be pulled down further than the other arm."

Only one of the thirteen subjects purposefully changed from one successful strategy to another. He had used the equal proportions strategy successfully until he was confronted with a problem that necessitated balancing a second set of weights on one arm. Then he explained that via equal products the solution was obtainable while by his earlier procedure it was not. Only one student brought forth technical scientific concepts in dealing with this task. It was the same student who had done so for the Floating/Sinking task. He consistently explained his predictions of the placements for weights in terms of the concept of torque---"if the product of the mass and distance out on one arm is equal to the product of mass and distance on the other arm, then the sum of the torques are zero and the balance won't turn."

If this task is regarded simply as demanding correct calculation of values via an equal products formula, then it is not necessarily a measure of formal operational thinking, for one may remember the formula and employ it by rote. The subject would not then become involved in structuring the problem with proportions at all, let alone thinking out systematically a means of compensating for the weight-distance values of one arm by using a variety of possible weight-distance values of one arm by using a variety of possible weight-distance combinations on the other. It is in working out these facets of the task and proposing a principle of the balance that formal thought becomes necessary. Our college subjects, most of them, were unable to come forth in the interview with a proposed principle other than the simple equal products formula they had remembered as a special key for solving this particular sort of problem. Only the subject who was at home with the concept of torque came forth with explanations that afforded a view of our balance problems as one subset of a variety of problems involving torque.

Reflecting on the range of views and strategies that were presented by our thirteen college age subjects, one must relinquish hopes of developing formal operational reasoning on the part of large segments of the college student population via the sorts of instructional experiences they represent. Formal college level science courses in physics and chemistry are in the backgrounds of eight of our subjects, and one subject had only one college level physical science course. For the most part those science courses met in large classes and were evaluated in cookbook, short answer, or multiple choice exams. On these exams it is quite possible for the students to answer the exam questions correctly without understanding what their "answers" are supposed to mean. Remember our subjects who gave an appropriate definition of density but went on to focus on surface area instead of volume?

Their general lack of willingness to use the materials and apparatus available in the interview situation to explore the behavior of the things and to generate their own ways of "finding out"--this lack is alarming. It signals the chronic discomfort of students with the concepts and workings associated with science (no matter how ordinary these objects are). Without entering into such active exploration, they remain ill prepared to invent for themselves key concepts of science and, therefore, they will continue to isolate themselves from having to deal directly with scientific notions and procedures. Thus, the outlook for having an intelligent and responsible public in the future to reasonably evaluate the products of science, of science education, or the values or ethical issues implied by the directions of science is grim, indeed.

It must be mentioned in concluding this paper that all the students (unpaid volunteers) who were interview subjects became directly involved in the tasks, took the questions seriously, and cooperated fully. Most expressed their appreciation for being allowed the opportunity for the experience. They all believed they had gained something of value for themselves by undertaking the project. That indicates, I believe, that they felt enriched by the experience and might be encouraged to do more if the settings are not so intimidating that their egos cannot abide the possibility of revealing what they "don't know."

Literature Cited:

Inhelder, Barbel & J. Piaget. ***The Growth of Logical Thinking from Childhood to Adolescence***. Basic Books, N.Y. (1958)

Note: Two color videocassettes were available showing college students doing the Floating/Sinking Objects Task and the Equal-Arm Balance Task.