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Constructing Solutions to the Problem of Solving Physics Problems

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CONSTRUCTING SOLUTIONS TO THE PROBLEM OF SOLVING PHYSICS PROBLEMS

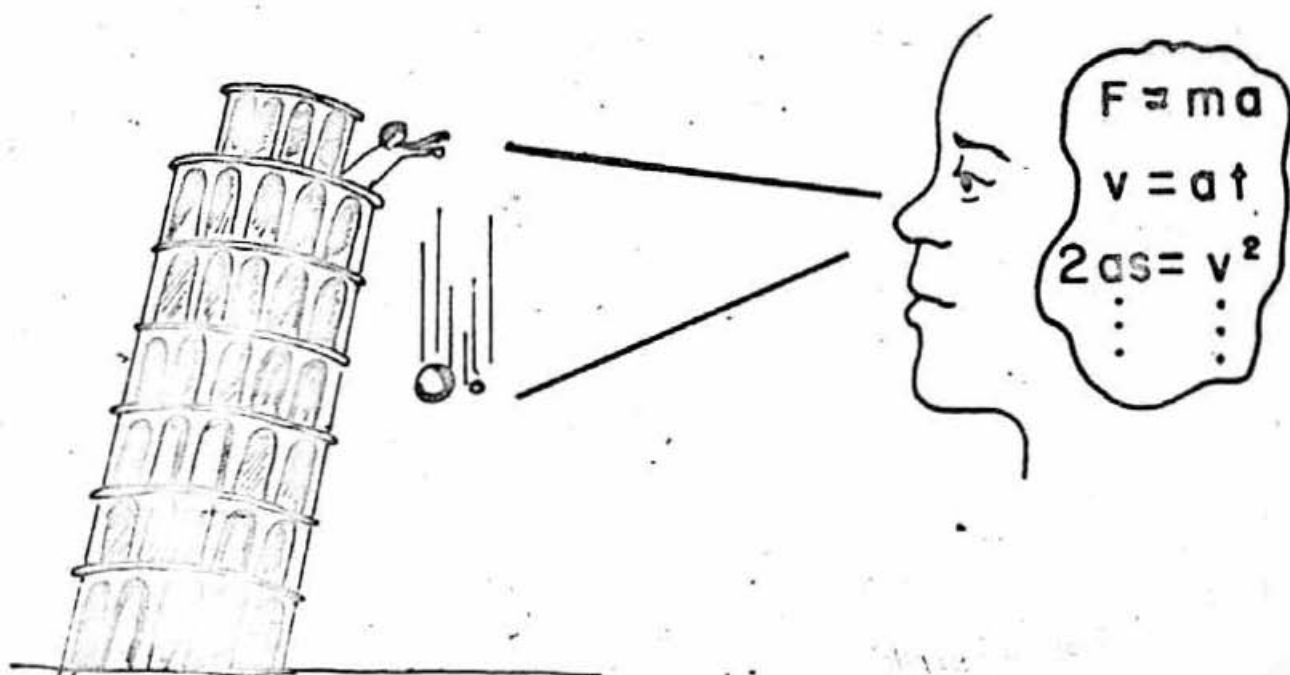


Figure 1

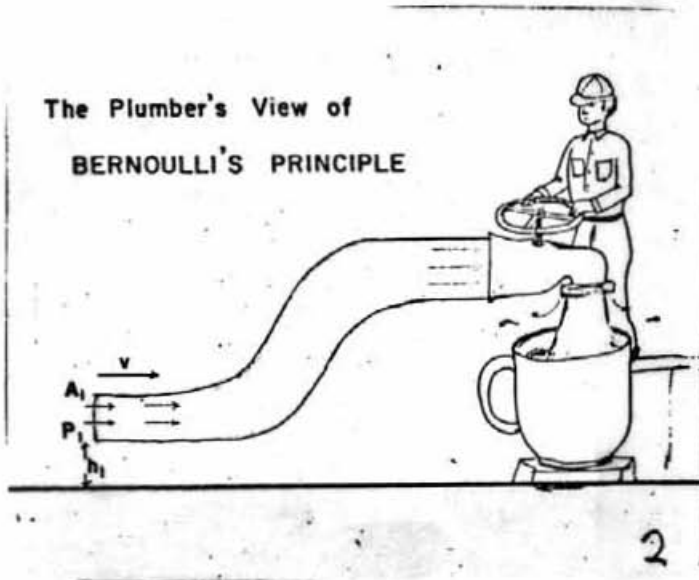
CONSTRUCTING SOLUTIONS TO THE PROBLEM OF SOLVING PHYSICS PROBLEMS

A revised transcript of an oral presentation given by Dr. Robert G. Fuller, Professor of Physics, University of Nebraska-Lincoln at the AAPT/APS meeting in San Francisco, California January, 1982.

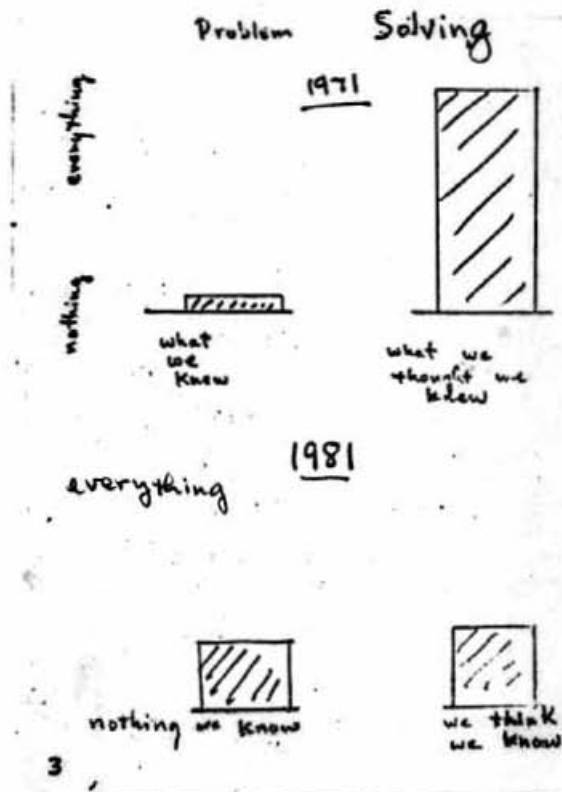
In this presentation I will lift up for you some of the tentative answers that have been found to the question of how do people solve physics problems. This presentation is as much inspirational as it is informational. It is the intent of these remarks to provoke you into investigating the current research on how people really do solve physics problems.

Before you launch into the main part of this text, I want to make you aware of my point of view on these matters. I am primarily a classroom practitioner.

(Figure 2) My interests in cognitive processes, development of reasoning, are practical. This paper represents an analogy to a plumber's view of Bernoulli's principle. Bernoulli's principle describes the idealized flow of a fluid. A plumber is primarily interested in the delivery of the liquid to the end user. Similarly the theories of cognitive processes of problem solving are interested in the theoretical explanations. The classroom teacher is interested in the end product, that is, can the student, in fact, solve problems on homework assignments and examinations.



The interest in the theory of problem solving in physics is relatively new. (Figure 3) In 1971 there wasn't much written about the difficulties that students have in problem solving. It was thought that it was known how physicists solve problems and it was known how other people go about solving physics problems. On a scale of knowledge about problem solving it was thought that practically everything was known. There appeared to be little need to try to figure out anything more about it. The decade of research since 1971 has shown that in 1971 very little was known about how people actually solve physics problems. Now considerably more is known about problem solving in physics and it is believed that considerably less is known than was thought to be known in 1971. Today there is a much more realistic appraisal of problem solving in physics, how it is done and how students might be enabled to do it.

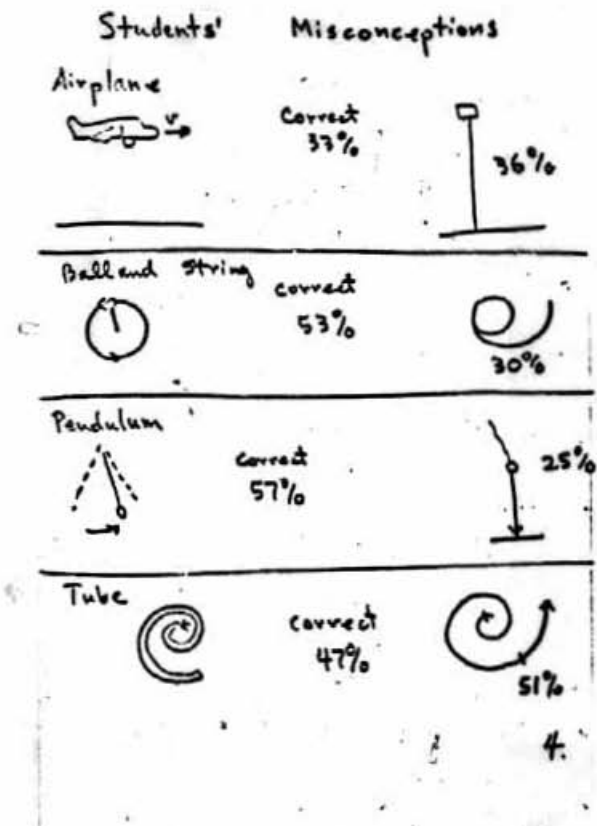


The first article that I remember seeing that raised the question of whether we knew all we ought to know about problem solving was an article that appeared in the American Journal of Physics written by McKinnon and Renner in 1971.¹ Since that time there has been a tremendous amount of activity not only by physicists such as Karplus, Arons and others but also by cognitive psychologists such as Larkin, Glaser and Simon. They have approached the problem of problem solving and many of them have used physics contexts in the problems that they studied in their research. There are three big ideas that have grown out of this research.

STUDENT MISCONCEPTIONS

The first one is that we now have a much better insight into the student's misconceptions about physics than we ever had before. The solid research in this area has come from people who have been following in one way or another the semi-clinical interview techniques developed and made famous by Piaget in his interviews with small children. A number of groups - Lillian McDermott's group at the University of Washington-Seattle, Jack Lockhead and John Clement at the University of Massachusetts-Amherst, and John Gilbert and his co-workers in England - have developed systematic processes by which students are interviewed about physics problems. The students' misconceptions about how physics works have been detailed in these studies. Perhaps none of those received the wide spread distribution of the article that was published in Science magazine.² In that study students gave written responses to some questions about moving objects. (Figure 4)

- (1) There was an object dropped from an airplane which was traveling with constant velocity v . A third of the students gave the correct parabolic path for the projectile and more than a third of the students showed the object falling vertically to the ground, not moving forward with a velocity equal to the velocity of the airplane. (2) Another question was about a ball being swung in a horizontal circle on the end of a string. If the string were cut, what direction would the ball go. Half of the college students said it would go forward in a straight line but 30% of them showed the ball going out in a spiral path. (3) A pendulum problem asked students what would happen to the bob swinging at the end of the pendulum if the string were cut. More than half the students gave the correct answer but 1/4th of the students showed the bob falling vertically to the ground. (Figure 4) A fourth question had to do with an object that was injected into a horizontal spiral tube. What happens when the object comes



out of the end of the tube, if it is rolling on a horizontal table? Almost half the students suggested that it would travel in a straight line but slightly more than half of the students said it would continue to spiral around on the table.

The implications of the results of all the studies of students' misconceptions of physics and physics problems are clear. (Figure 5) The classical view of learning about problem solving is wrong! The view I inherited in my graduate training as a research physicist indicated that the student was an empty vessel



Prof Student
**CLASSICAL VIEW OF
LEARNING
PROBLEM SOLVING**

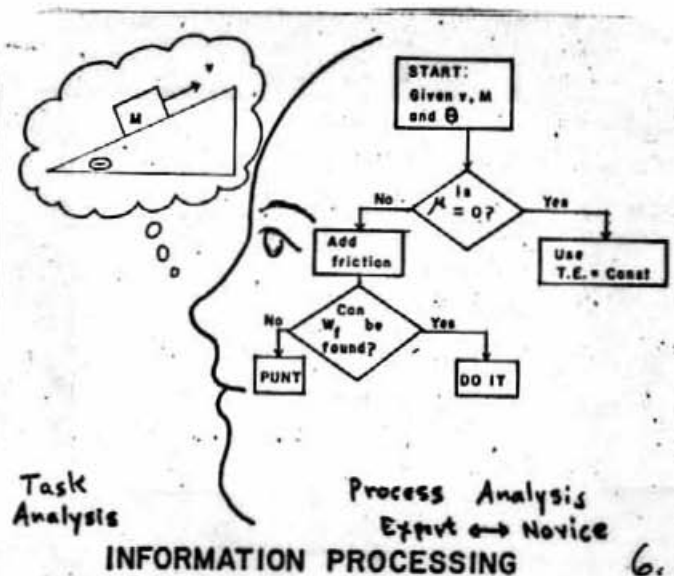
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into which professors poured the knowledge of physics equations, of functional relationships and of problem solving strategies. The last ten years of research into student reasoning about physics problems clearly indicates that that is not the case. The mind of today's student is a jungle of Aristotelian and pre-Aristotelian ideas about nature and the laws of physics. The student has had experience pushing objects with a constant force and they do not go in a straight line with ever-increasing velocity. Therefore the explanations of the way objects move given to these students by the physics professor are placed in a special category of unlikely and useless ideas to be mastered only for a particular course. The problem of rooting out wrong ideas about nature, about physics problems and about problem solving is more difficult than trying to teach students who had no ideas about physics whatsoever. A professor who wishes to teach his or her students good problem solving strategies has to consider the present understandings of his/her students about nature and about the way the laws of physics work. A professor needs to understand the peculiar strategies for solving problems that students already use. It will be a more difficult task to start where our students are in the problem solving process than if one could start at zero where they had no strategies at all.

Students, in fact, have prejudices in favor of the wrong way of doing things. It is more difficult for teachers than if students had no ideas whatsoever. This is the first issue that any physics professor who wishes to teach problem solving to his students must take seriously. How can he develop a strategy in his classroom to carve out some highways to good problem solving through the jungles that infest the minds of the students?

INFORMATION PROCESSING

There are two different schools of researchers who have studied the reasoning, or problem solving, strategies used by college students. The first of these schools is called Information Processing. (Figure 6)



This school of research has two key ideas that can be very helpful in the teaching of problem solving to students. First, these researchers have been extremely skillful at analyzing tasks. Many of them have performed very clever task analyses and devised systems of questions about a physics problem that allows them to determine the processes that are going on in the mind of the student. Many physicists have been solving physics problems for so long that they have not recently analyzed the reasoning requirements of the various problems that are assigned. Nor have they thought systematically about the problem solving demands of the questions that are asked on examinations. The same kinds of problems have been used for so long and they seem so straight-forward that the reasoning process necessary to solve them has not been examined. The information processing

researchers help us understand how to go about the process of analyzing physics problems.

In addition, these researchers have been trying to understand the processes that are going on in the minds of people when they solve problems. A most notable area of this research is the comparisons of expert and novice problem solvers.³ What are the distinctive characteristics between the physicist who has solved physics problems for twenty years and the beginning students who have been solving physics problems for 20 days? Of course a professor has a larger knowledge base to bring to any given problem than a student. Perhaps more importantly the professor has developed a strategy of organizing that knowledge into "chunks" of information that can be called upon to solve a particular set of problems. A student seems to lack the connectedness of knowledge that a professor has. A student begins by searching through all of the trees in the forest for some possible way of making a path to the solution. The professor by having knowledge organized in useful unities can call upon the one or two strategies that are likely to be the more successful. How does the professor or teacher go about helping students develop the "chunks" of knowledge in ways that help them in problem solving? How can a professor help students organize their knowledge in a more global way so they can see how to apply various pieces of it to different kinds of problems? One of the answers to these questions is that a general problem solving strategy needs to be taught explicitly to the students. Students need to be given explicit, clear instructions in the physics classroom about how they ought to organize their own thinking as they try to go about solving problems. For example, the D-P-I-C strategy was described

in the paper by Reif, Larkin and Brackett in the American Journal of Physics in 1974. They argued, on the basis of their research, that this four part strategy reflects the kind of problem solving strategy that experienced problem solvers use when they solve problems. (Figure 7)

CLASSROOM APPLICATION

A general problem solving strategy needs to be taught:

D - P - I - C

Describe

Plan

Implement

Check

(Implies a reduction in content coverage.)

Figure 7

The first step in this D-P-I-C strategy is to Describe the problem. The student should state the problem in his/her own words. The student should be encouraged to verbally and pictorially explore the problem, draw a figure or diagram. The student must be sure to understand exactly what is given, what the assumptions are and what can be neglected. Can the student restate the problem and ask questions about the problem in his/her own words? That is the first step. This is one of the most difficult things to get beginning students to do. They do not like to write down what is given; they resist drawing diagrams. They want to begin immediately to multiply numbers. The experienced problem solver always starts with this step to make sure the description of the problem is clearly understood and the assumptions that are to be taken into account to solve the problem are clearly formulated at least in his/her mind. This is the first thing we must demand of students. They must learn to

describe problems in their own words so they understand the conditions of the problems.

The second part of the D-P-I-C strategy is to Plan a solution. What kinds of knowledge will be useful in solving this problem? How can this knowledge be systematically used to solve this problem. Frequently in physics this step calls forth some algebraic relationships and equations which give the relationships among the various quantities in the problem. How can one proceed from what is given to the solution? Planning a problem solving strategy makes use of empirical and algebraic relationships.

The third part of this problem solving strategy is Implementation. To implement the plan of solution often means putting numerical values for quantities in algebraic equations and computing a numerical result. To implement the planned solution saves all the numerical calculations to the end. Beginning students start by putting numbers into the equations and they lose sight of the relationships between the

variables. They are not able to simplify their results. They don't see how the quantities are related to each other. Students must do a general plan first and implement afterwards.

After a solution has been obtained, the final part of problem solving is to Check the result. Does the result make sense? How does the answer fit with ones own experience of nature and ones own sense of how the problem might have worked out if one had guessed at the beginning. If one is pushing on a vehicle in the forward direction and one gets a velocity or acceleration in the backward direction, does that make sense? Consider variations of the problem. What happens if the mass is doubled or the force is doubled or a quantity goes to zero? Do the results obtained for the problem still hold true?

These are four steps in a problem solving strategy. Describe the problem, plan a solution, implement the solution and check the result. To teach explicitly a problem solving strategy implies a reduction in the physics content covered in a course. A class cannot explicitly study this problem solving strategy without leaving out some topics of physics that are usually treated. Problem solving is very important! Physicists must take the time to teach it in an overt way. Do not assume because students have solved homework problems that they have developed adequate problem solving strategies.

CONSTRUCTIVISTS

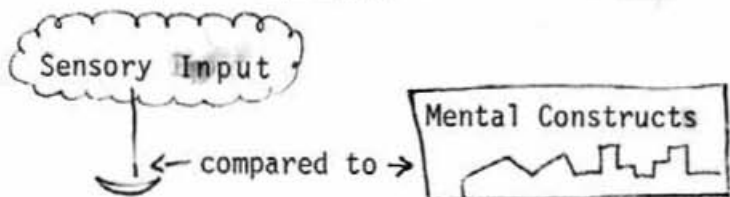
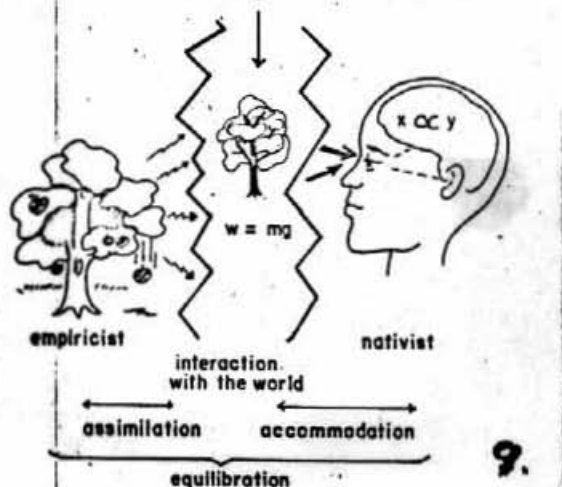
PIAGETIANS - NEO-PIAGETIANS



The second group of researchers are called constructivists. These are people whose research has grown more closely out of the work of Jean Piaget, the Swiss genetic epistemologist. In contrast to the information processing people who have tended to focus more on the external aspects of problem solving, the constructivists have talked more about the internal mental processes by which strategies of problem solving are constructed. They have used the mental modeling clay concept of reasoning where a person has the flexibility to change the mental structures that are used to solve problems as the person constructs solutions to problems. (Figure 8) One of the most helpful aspects of this school of researchers is their philosophical understanding of what knowledge is and how new knowledge develops.

HOW ARE NEW SCHEMES DEVELOPED?
WHERE DOES "KNOWLEDGE" ARISE?

MODERN PHYSICISTS, PIAGET
ARE RADICAL CONSTRUCTIVISTS.



mismatch produces
disequilibrium

leads to additional input and/or
reorganized mental constructs
(assimilation/accommodation)
to reach
Equilibration
until challenged by another
conflict between
input and expectation.

Self-Regulation

Figure 10

Piaget has suggested the dynamic interaction model of assimilation-accommodation-equilibration as the way knowledge and problem solving strategies are constructed. This problem is the mental equivalent of the homeostatic process that takes place in living systems; it is the process of self-regulation. This model sees the development of knowledge as a self-regulation process in which one's experience of nature through sensory input is compared with one's interior understanding of nature through one's use of mental structures. When these two things do not match, when our experience does not match our understanding, dis-equilibration occurs. Piaget argues that human beings are naturally led to seek additional experiences of nature and/or reorganize the way we construct our understanding of nature through the process of assimilation and accommodation. We mentally evolve to a state of equilibration in which we can understand the things that confused us. We are temporarily equilibrated until we are challenged again by new experiences which do not fit our understanding. (Figure 10)

Modern physicists and Piagetians are what might be called radical constructivists. (Figure 9) There have been schools of scientists and philosophers who were empirists. They believed that the laws of nature were external to the minds of man, that anyone who looked at nature would discover exactly the same laws. For example, they believed, Newton's laws did not need to be named for Newton; these laws were THE laws of Nature. Nature speaks with one, unique voice. That is the empirist view of Nature. At the opposite extreme, there have been Nativists who believed that nature is a jungle of random processes and that the laws of nature exist innately in the minds of human beings. Logic and mathematics are innate to mankind and are the unique structure to explain the processes of nature. Modern physics has rejected both the empirist and nativist views of nature. The revolution of modern physics seems to be that the laws of physics and the minds of physicists are somehow combined together. It is in the experience-mind interaction that understanding is constructed. The laws of nature are built at the interface between our sensory experiences of the external world and our reasoning about those experiences. Nature is an open system - always inviting us to understand her works in different ways as we transform our sensory data through ever evolving mental constructs.

In this kind of model of dynamic interaction between the minds of people and their external experiences, the time when we are most likely to develop new understandings and new strategies is when our present experiences do not fit our mental preconceptions. This period of disequilibrium, of being slightly confused, is the time when we are most likely to make intellectual growth. The classroom implications of this model (Figure 11) are that professors need to provide external

Classroom Implications

1. "Concrete" experiences to analyze

a) In an environment where understanding matters

i) small groups

2. less content

concrete experiences for the students to analyze, experiences which are likely not to match the students' conceived ideas of the way physics laws ought to work. In fact, laboratory activities and classroom activities ought to be designed to be slightly confusing to the students given to their present mental constructs. Students need to be confronted with these tasks in an environment where understanding them makes a difference, not just understanding to please a professor, but for their own self-esteem and their own self-confidence and mental equilibration.

Figure 11

In our ADAPT program,⁵ based on these ideas, we have used small group work. The importance of peer relationships in solving problems, in encouraging students to attempt more difficult problems, and in talking about their own processes of solving problems is very important. We have less time to spend talking about the laws of physics and our own understanding of these laws if we are going to give students the opportunity to experience firsthand the behavior of Nature and require them to construct their own sense from her rules.

Finally, the work that has most recently come to my attention is the work Thomas Malone has published in his study "What Makes Things Fun to Learn."⁶ What are the features of learning that intrinsically motivate us to solve physics problems? Malone, in his published articles, has highlighted three features: i) the sense of challenge to achieve some goal at the end; ii) the role of fantasy (or story problems?); iii) cognitive curiosity. We are motivated by being puzzled about the way things turn out and pursuing it until we are able to satisfy ourselves that we understand nature. I think every physicist has gotten into his career as a physicist because of this sense of cognitive curiosity that he/she has about nature and the way nature behaves. Somehow, if our students are to be effective and intrinsically motivated problem solvers the sense of challenge and fantasy and cognitive curiosity that has provoked us into this profession, needs to be shared with the students.

CONCLUSION

What can be done in response to all of the research in problem solving in the last decade? What follows is a list of what can be done, from nothing to quite a lot: Go to 11!

Ways you can respond to the content of this presentation

- I. Do nothing.
- II. Do a little bit
 - A. Write to Dr. D.R. Woods, Dept. of Chemical Engineering, McMaster University, Hamilton, Ontario, Canada L8S 4L7 to receive the P(roblem) S(olving) News(letter).
 - B. Read a little bit in journals about student misconceptions in physics:
Trowbridge & McDermott, AJP 49, 242 (1981)
Lochhead & Collura, TPT 19 (1), 46 (1981).
Fredette & Clement, JCST 10, 280 (1981).
- III. Do a little more.

Try teaching students to use a general problem solving strategy, for example the D-P-I-C system explained by Reif, Larkin, and Brackett, AJP 44, 212 (1976).

(Be sure you have tenure before trying any of the following.)
- IV. Do Still More.

Try to understand what the leading groups in research in physics education and/or problem solving are doing, e.g.

Lillian McDermott, Dept. of Physics, Univ. of Washington, Seattle, WA 98195
Robert Karplus, Lawrence Hall of Science, Univ. of California, Berkeley, 94720
Fred Reif, Department of Physics, Univ. of California, Berkeley, 94720
Jill Larkin, Psychology Dept., Carnegie-Mellon Univ, Pittsburgh, PA
John Gilbert, Inst. for Ed. Tech., Univ. of Surrey, Guildford, Surrey, England
Robert Glaser, LRDC, University of Pittsburgh, Pittsburgh, PA 15260
Jack Lochhead, Dept. of Physics, Univ. of Mass., Amherst, MA 01003
- V. Start to get serious - all of the above plus.

Talk on a regular, frequent basis to a psychologist interested in cognitive processes and problem solving. Try to read an article in instructional psychology from time to time. Scan the table of contents in J. of Research in Science Teaching regularly.
- VI. Serious - All of the above plus.

Examine your teaching behaviors in the light of what you have learned. Change the focus of your teaching from being a content autocrat to emphasize problem solving and reasoning. Be prepared for flak. (You need to find a support group so go on to the next step as soon as possible.)

VII. Committed and Excited - all of the above plus.

Subscribe to your own cognitive psychology journal, e.g. The Genetic Epistemologist quarterly from the Jean Piaget Society, 113 Willard Hall, College of Education, Univer. of Delaware, Newark, DE 19711.

Find or organize a group of like minded faculty for mutual support. Try to put together a problem solving or development of reasoning program. Ref. Piagetian-based Programs in Higher Education, ADAPT, 110 Ferguson Hall, UN-L, Lincoln, NE 68588.

VIII. True Believer - all of the above plus.

Change graduation requirements to include reasoning or problem solving, e.g. The Q Requirement, c/o Lou Smogor, DePauw University, Greencastle, IN 46135.

IX. For Fun -

Read and reflect on Thomas Malone's "What Makes Computer Games Fun?" *Byte*, Dec., 1981, and "Toward a Theory of Intrinsically Motivating Instruction", *Cognitive Science* 5, (4), 1981.

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- ⁵Fuller, R.G., et. al. Piagetian-based Programs in Higher Education, UN-L, 1980.
- ⁶Malone, T.W. "What Makes Things Fun To Learn?" *Byte*, December, 1981.