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Chapter 8: Content Versus Reasoning: A Physics Instructor's Struggle

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CHAPTER EIGHT

Content Versus Reasoning:

A Physics Instructor's Struggle

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Whenever I am asked to teach a physics course I know what content I should cover. Even if the college catalog description of this course is brief and couched with generalities, I have a professional assurance that I know what physics topics to teach. During my years of graduate training and physics research I have come to embody the orthodoxy of physicists. Name a physics course, such as thermodynamics, or modern physics, or general physics, and I can immediately think of a list of topics to be taught in such a course. I can also name a textbook, or two, that can be used for each course. Consider a course called general physics. No doubt it includes the topics of mechanics, heat, sound, light, electricity, and magnetism, and modern physics. Probably with the topics taught in the sequence I have just listed. While my colleagues in physics might argue with me about a few items to be included in each topic, we would share broad areas of agreement above course content. That is one comfort to be found in being a physicist.

This orthodoxy of physicists is not based purely upon blind faith. After all, energy is a central concept in physics. In a general physics course energy and its various forms should be given a major role in shaping the course content. But energy is a quantity that can be calculated from the various properties of a system. Energy is calculated from the forces and the motions of a system and its parts. Then the study of forces and Newton's laws of motion must precede a study of energy. But before we consider the action of forces which cause objects to move, we should know about the properties of moving objects. We need to study kinematics. So there you have it, a linear chain of topics leading up to energy, i.e., start with kinematics, through forces and Newton's laws, to energy.

Energy is a computed quantity, not directly measurable for any system. Nevertheless, concrete examples of systems with more and less amounts of energy can be demonstrated for students so that the concept of energy can be made reasonable and concrete for many students. In the usual linear chain of topics, a student will need to understand forces before studying about energy. Forces do not seem to be difficult. After all, a force is just a push, or a pull, on an object. But the same size force acting down on a table top can have a different effect from a force acting horizontally on a top of a table. The quantitative effects of a force are complicated by the vector nature of forces, i.e., the effects of a force depend upon the direction in which the force is acting. Suppose you have two forces acting on an object and each force has a size of three, the net effect of these two forces added together is equal to a single force with a size from zero to six, depending upon the relative direction of the two forces. Therefore, forces, which serve as a content prerequisite for energy, possess a property which may make forces more difficult to understand than energy itself

The effects of forces acting on an object can be observed in the motion of the object. So kinematics, the study of motion, serves as a content prerequisite for forces. Unfortunately, not only do such kinematic quantities as velocity and acceleration have vector properties, but acceleration is the ratio of a ratio, i.e., the time rate of change of the time rate of change of the displacement of the object. Once again, the prerequisite of a content area in physics (kinematics) contains reasoning tasks that seem to be more difficult than the subsequent content areas (forces and energy).

In short, topics to be studied in a physics course are arranged in a usual, or orthodox, sequence. This orthodox sequence has a rational basis, but this basis may not include a consideration of the level of reasoning required to learn each topic. A physics course which is used to foster the development of study reasoning abilities must progress from lower to higher reasoning levels. Consequently, such a developmental physics course may have a sequence of physics topics which contrasts with orthodox physics courses.

The ADAPT program presents a curriculum development problem to a physics instructor. One needs to design a sequence of physics learning cycles for college students which will begin with concrete reasoning abilities and lead to the more advanced reasoning abilities while preserving the content integrity of physics.

After the first year of the ADAPT program, I wish that we could say that we had been able to solve that problem. I think that we are a bit more like Thomas Edison when he reported that he now knew 299 things that did not work. So let us begin with some of the learning cycles that did not seem to be effective.

Forces and their components seem inaccessible to most students. Never have so many students spent so much time on such a small concept and shown so little mastery of it. Maybe the components of forces is not a very useful concept anyway. If the student would just use vectors and their components in economics or in English or in history (I wonder what the components of a revolution are and what direction does a revolution point?), perhaps the study of vectors could be more easily justified.

The use of similar triangles or similar trigonometric functions to compute unknown, unmeasurable distances did not come easily. We recognized that these exercises required the students to use proportional reasoning, so we tried to design them to the use of triangulation for measurements left many of the students confused and they sought private counseling with the mathematics instructor. I believe that such experiments are close to the developmental ability of ADAPT students and that if we redesign our exercises we can show better success next time.

Experiments for concrete operational students that can lead to the concepts of potential and kinetic energy in mechanical systems were difficult to design and were not easily used by the students.

Some experiments provided data which required some transformation before a linear relationship between the variables could be found on a graph. In general, these experiments were not helpful. For example, the students collected pressure versus the volume data for a confined gas. The curve of the pressure versus the inverse of the volume is liner in Cartesian coordinates. The transformation of data into a different format (in this case, taking the inverse of the volume) was not learned by most of the students, even with substantial instructor input.

There were some experiments that seemed to work quite well. The metric system was made to seem necessary and useful through an international bartering exercise which also helped introduce numerous economic variables. Graphical techniques were stressed and the students did learn how to use Cartesian coordinate graphs to find the algebraic relationship between the variables for linear function. They also learned to use both log-log and semi-log graph paper to determine the more complicated functional relationships of

$$y = A\ x^{n} \text{ and } y = A\ 10^{mx} .$$

Periodic motion and simple harmonic motion were properly analyzed by the students.

When the topics that were successfully understood by the ADAPT students are considered, we find an almost random collection of topics usually covered in a general physics course. The topics used with success in ADAPT physics are a small subset of the usual course. The sequence of topics seems to lack a rational basis. Several more years of ADAPT teaching experience is needed in order to find a more satisfactory developmental course in physics.

In concluding this chapter, I want to try to generalize on my experience with the physics component of ADAPT and try to express my impressions about what has happened in the other ADAPT disciplines during this project. I would like to believe that professors who think formally about their discipline are able to sit down in a quiet place and carefully analyze the structure of their discipline into a sequence of topics that increase montonically in terms of the level of reasoning required of the students. However, I think our experiences in teaching the ADAPT program indicate otherwise. We can evolve college courses that encourage the cognitive self-regulation process with the content topics of our discipline. The response of our students provides the disequilibrating force and, I hope, our continued efforts at improving our program keeps us nearly equilibrated. Finally, the task of evolving an effective college program for the development of college students reasoning abilities is much larger than the ADAPT program. We want to encourage many other faculty members who are engaged in a similar evolutionary process to share their insights and successes with us. Then, at last, perhaps we can impose some order upon the apparent chaos of our present efforts.

Addendum added in 2007: This essay was written in 1976 after one year of the ADAPT program which lasted until 1997. Over the years a physics course that was laboratory based and did hands-on activities that produced linear functions, then power law functions and finally exponential functions developed. The students used Cartesian graphing, log-log graphing and semi-log graphing skills and their ability to determine which graphs to use for which kinds of data analysis. From the early 1980s the second semester course was entitled ***Problem Solving Using Computers*** and involved the students in learning to use a variety of computer software packages to solve a wide variety of problems, including doing a computer project for a non-profit organization in Lincoln. It is intended that the lessons from those courses will eventually be available on the Digital Commons website.

