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ABSTRACT

A student-computer dialog for teaching a mathematical proof proved effective when tested in two university physics courses. The objective was to make the beginning or intermediate physics student an active participant in the development of the proof, which concerned the conservation of mechanical energy for a mass moving in one dimension and subject to a force that depends only on position. A suitable computer flow chart was written, then the program was tested in two university settings and feedback was sought from students. The few problems encountered concerned computer terminology and student choice patterns. Thus the student-computer dialog seems useful in teaching mathematical derivations, the staple of many science courses. (RB)

A COMPUTER-BASED DIALOGUE FOR DERIVING ENERGY CONSERVATION FOR MOTION IN ONE-DIMENSION*

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July 17, 1970

ABSTRACT

This paper describes a student-computer dialogue for beginning or intermediate physics classes. The dialogue enables the student to take some initiative in showing that energy conservation in one-dimension is a consequence of the laws of motion.

*This project is supported by the National Science Foundation.

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Physics, mathematics, and other science courses, use the mathematical derivation or proof of a result, starting from some other theorem or physical principle, as a staple of such courses at the beginning, intermediate, and advanced levels. Such derivations often constitute the main portions of lectures and textbooks; in a mathematics course they may constitute the entire course.

A derivation can serve several purposes. First, a particular result is needed, often an important result useful to the student in future work. Secondly, as teachers, some of us are eager to show that classical physics can be developed as a well-constructed logical net, and that austere beginnings can yield powerful results. A third and perhaps more important reason for derivations in physics courses is that we hope to teach students the "art" of deriving physical results. A complicated derivation often involves much trial and error. We want to help students become sophisticated at deriving results. Teaching the techniques of proof is one of the most important goals of physics courses, and it is one of the hardest goals to accomplish. (George Polya's How to Solve It is one attempt to teach this art.)

Many teachers have heard the archetypal student's comment on a complicated proof presented in lecture. The student announces that he could follow the proof, but he does not feel he could find the derivation himself! This hardly surprises the teacher, who may not, on first encountering the problem, have produced the derivation as facilely as he duplicated it in lecture. But not realizing that everyone gropes initially, the student feels insecure because he cannot generate quickly such a smooth and elegant proof. (It could be argued that the less polished lecturer might provide better insight as to how proofs are developed than the person who carefully prepares and rehearses an elegant derivation.)

The Energy Conservation Dialogue

The computer dialogue described here is designed to make the student an active participant in the development of the proof, to let them take at least some of the steps along the way on their own. Some of these steps can be large, while others will be relatively small. At worst, the dialogue corresponds to something like the lecture situation, where the student is told the proof; however, he probably receives more detail than in lecture, through the remedial sequences in the dialogue.

The dialogue develops a proof of the conservation of mechanical energy for a mass moving in one-dimension and subject to a force that depends only on the position. The proof starts with the law of motion; we multiply by the velocity and write the resulting equation in the form

$$\frac{d}{dt}\text{ (something)} = 0.$$

In the process of the proof we introduce the concept of potential energy as the quantity whose negative spatial derivative is the force, and the student is asked to enter the potential energy and total energy for several different forces.

The first flow chart shows the general form of the dialogue, the second shows greater detail in one section, and the third is a page from the full flow chart.

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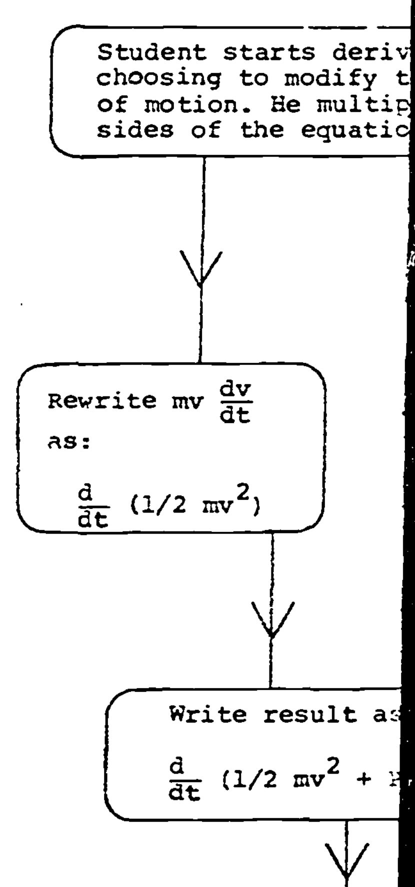

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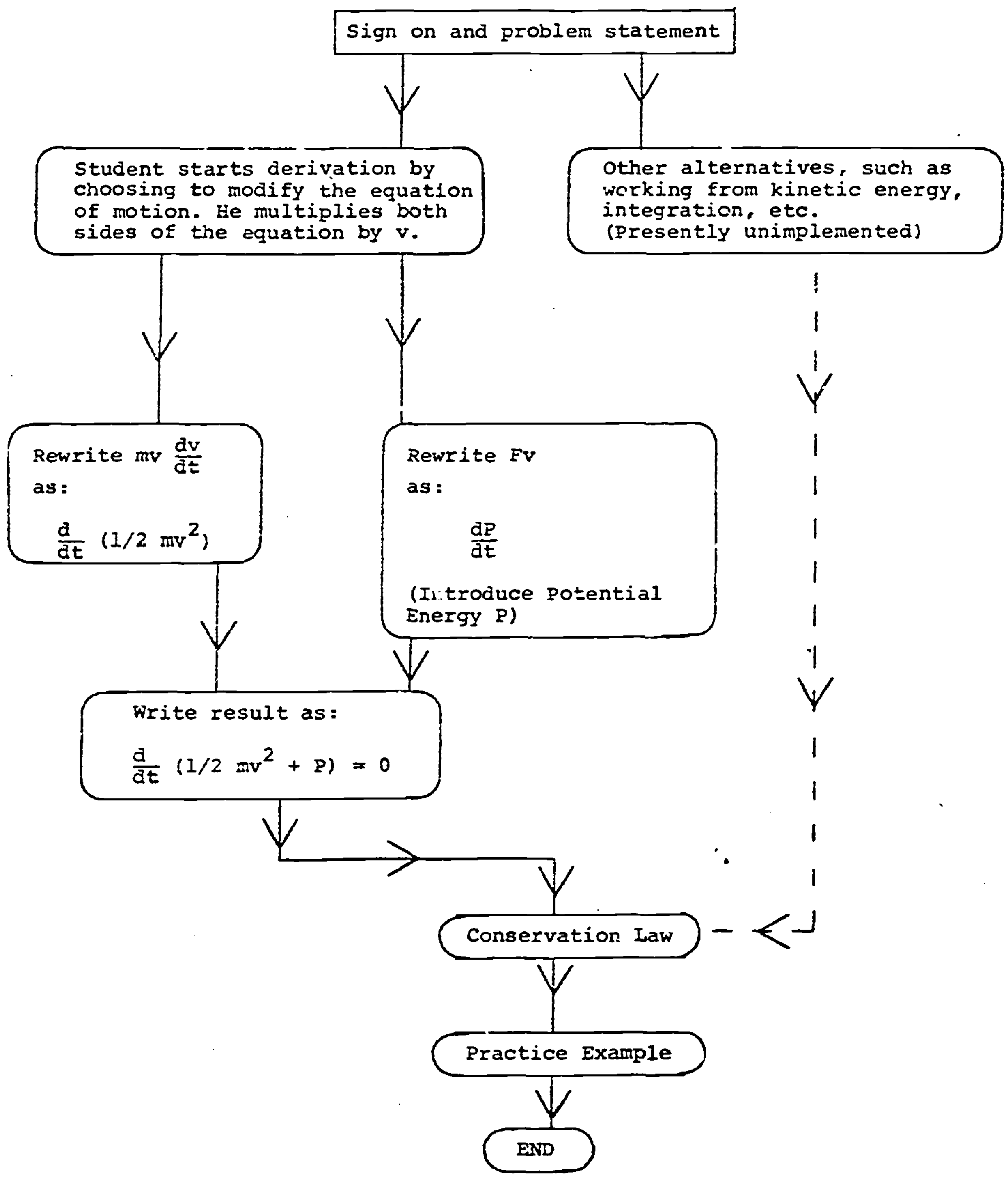
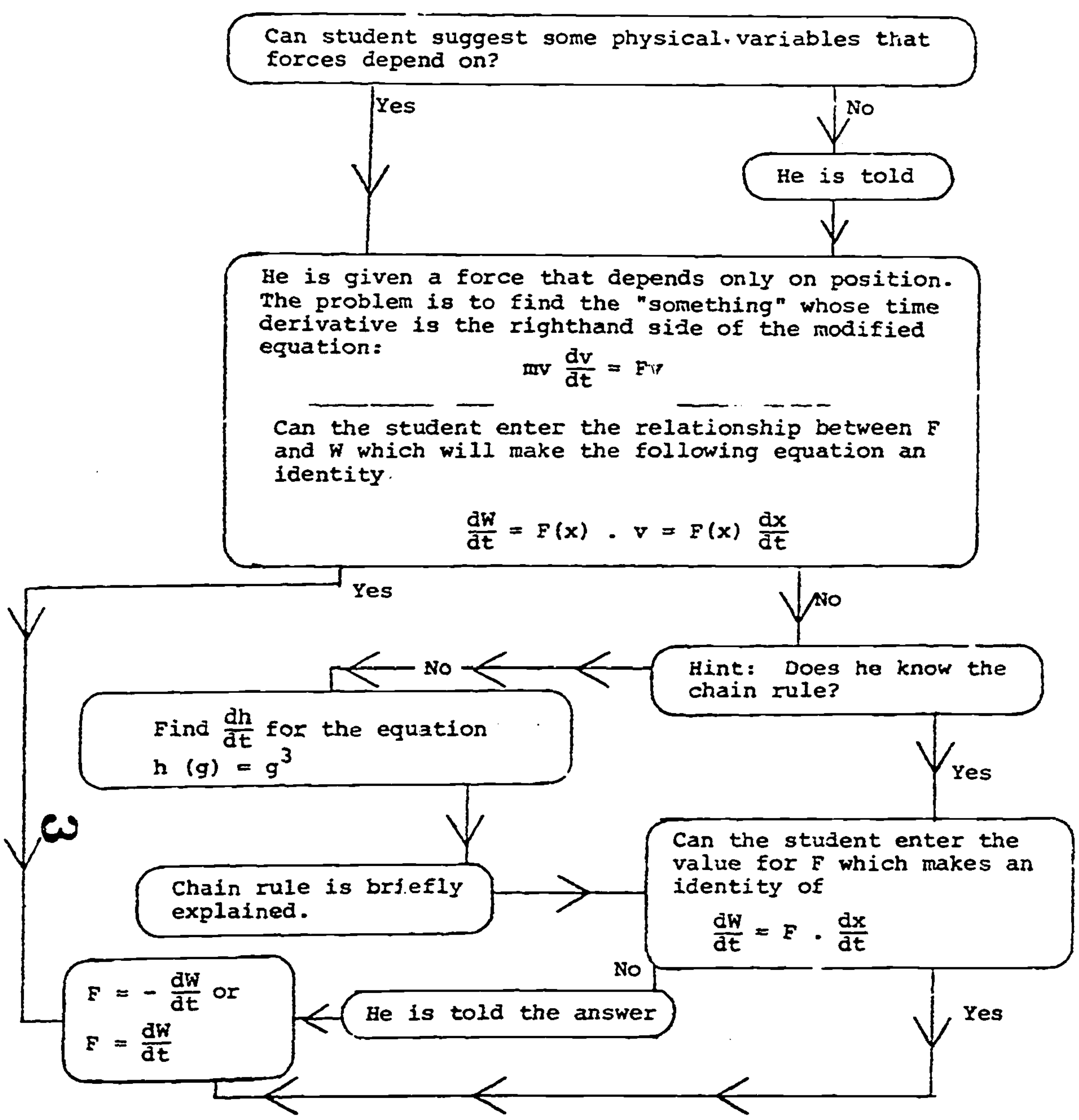
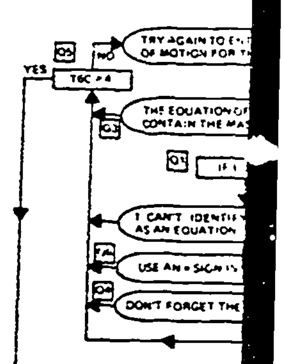
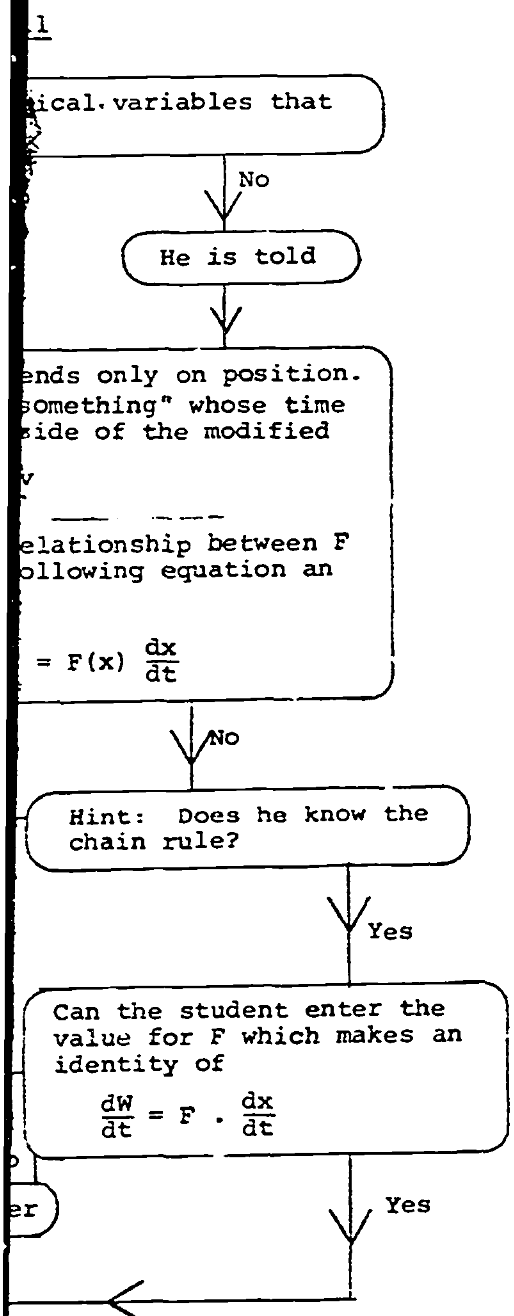
Overview of the Tutorial Program on Energy Conservation



Blow-up of One Section - not full detail







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= F(x) $\frac{dx}{dt}$
No
Hint: Does he know the chain rule?
Yes
Can the student enter the value for F which makes an identity of
$\frac{dW}{dt} = F \cdot \frac{dx}{dt}$
Yes
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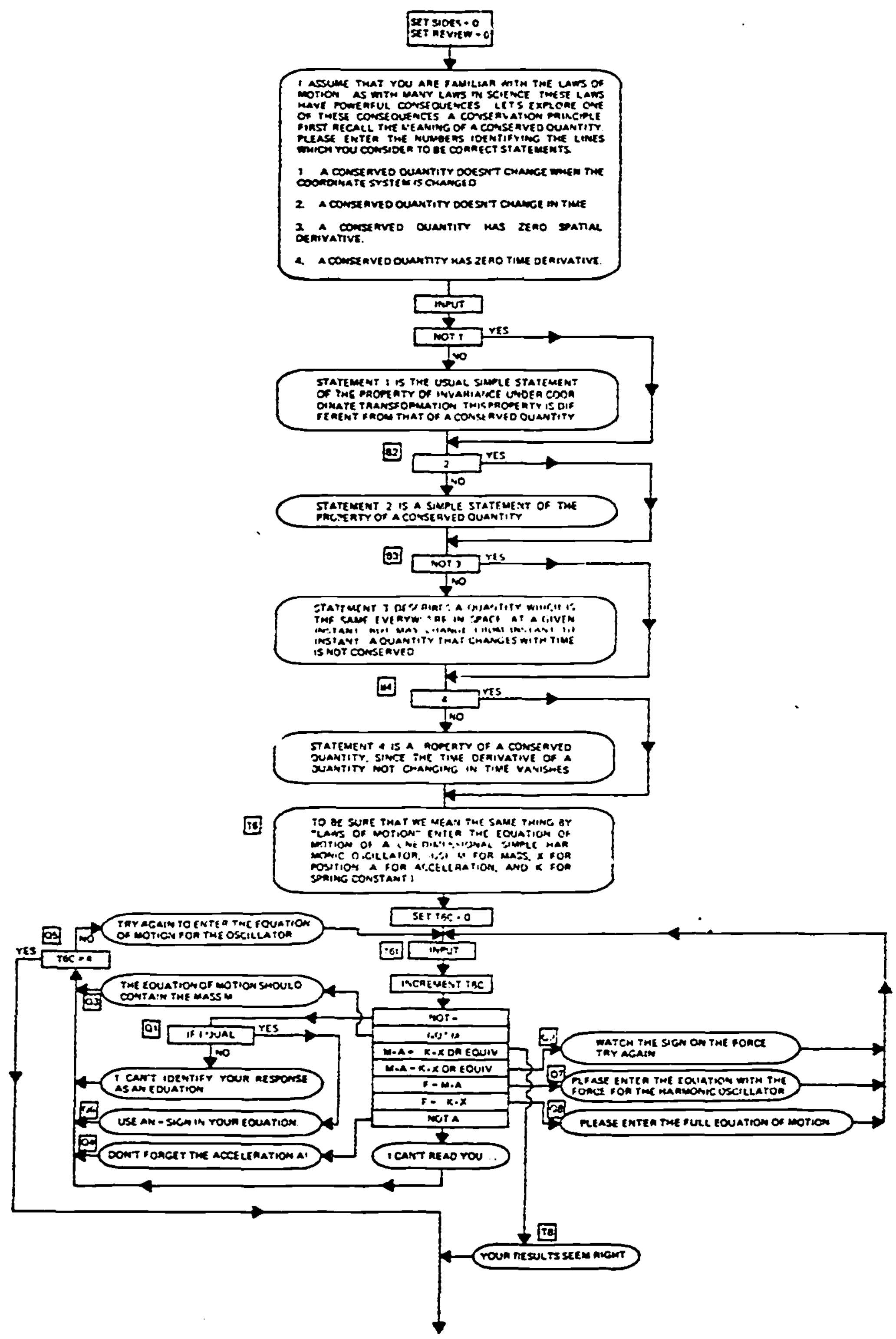

SET SIDES = 0
SET REVIEW = 0
I ASSUME THAT YOU ARE FAMILIAR WITH THE LAWS OF MOTION. AS WITH MANY LAWS IN SCIENCE THESE LAWS HAVE POWERFUL CONSEQUENCES. LET'S EXPLORE ONE OF THESE CONSEQUENCES, A CONSERVATION PRINCIPLE. FIRST RECALL THE MEANING OF A CONSERVED QUANTITY. PLEASE ENTER THE NUMBERS IDENTIFYING THE LINES WHICH YOU CONSIDER TO BE CORRECT STATEMENTS.
1. A CONSERVED QUANTITY DOESN'T CHANGE WHEN THE COORDINATE SYSTEM IS CHANGED
2. A CONSERVED QUANTITY DOESN'T CHANGE IN TIME
3. A CONSERVED QUANTITY HAS ZERO SPATIAL DERIVATIVE.
4. A CONSERVED QUANTITY HAS ZERO TIME DERIVATIVE.
INPUT
NOT 1
YES
NO
STATEMENT 1 IS THE USUAL SIMPLE STATEMENT OF THE PROPERTY OF INVARIANCE UNDER COORDINATE TRANSFORMATION. THIS PROPERTY IS DIFFERENT FROM THAT OF A CONSERVED QUANTITY
2
STATEMENT 2 IS A SIMPLE STATEMENT OF THE PROPERTY OF A CONSERVED QUANTITY
NOT 3
4
STATEMENT 4 IS A PROPERTY OF A CONSERVED QUANTITY, SINCE THE TIME DERIVATIVE OF A QUANTITY NOT CHANGING IN TIME VANISHES
SET T6C = 0
INPUT
INCREMENT T6C
T6C = 4
TRY AGAIN TO ENTER THE EQUATION OF MOTION FOR THE OSCILLATOR
THE EQUATION OF MOTION SHOULD CONTAIN THE MASS M
IF EQUAL
I CAN'T IDENTIFY YOUR RESPONSE AS AN EQUATION
USE AN = SIGN IN YOUR EQUATION
DON'T FORGET THE ACCELERATION A!
NOT =
M*A = K*X OR EQUIV
M*A = -K*X OR EQUIV
F = M*A
F = -K*X
NOT A
I CAN'T READ YOU ...
WATCH THE SIGN ON THE FORCE. TRY AGAIN
PLEASE ENTER THE EQUATION WITH THE FORCE FOR THE HARMONIC OSCILLATOR
PLEASE ENTER THE FULL EQUATION OF MOTION
YOUR RESULTS SEEM RIGHT

Development

The development of computer dialogues as a self-instructional resource is still relatively new, so a description of the process we followed may be of some interest. First we discussed which areas and approaches in physics might lend themselves to an effective computer-student conversation. Then we decided to pursue two dialogues, the one discussed here and another involving simulation in the study of plane electromagnetic radiation (a dialogue still under development).

The energy conservation proof was developed first as a flow chart showing what is typed to students, the expected responses, and the actions in each case. The two of us spent approximately three days working together on the flow chart, with occasional assistance from a student and a secretary. We did <u>not</u> use standard flow chart conventions.

The flow chart approach was appealing for a number of reasons. We were working at the University of California, Irvine, where a change was under way in computer facilities and no local computer was available. We were very concerned with the question of <u>spreadability</u> of such material. Computer dialogues have often existed only as computer programs in specialized languages, not usable outside the environment in which they were developed! The simplified flow chart seems a reasonable approach to developing computer conversations in a language-independent form. Furthermore we felt that pedagogical details should come first: we decided <u>what</u> we wanted to do, knowing something about the potentialities of the computer, before putting ourselves into the straight-jacket of a particular set of computer

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languages and facilities. We feel that successful use of the computer in education demands that learning details have priority over computer software details. In addition the flow chart furnishes a view of the dialogue to a teacher who is considering its use in his classroom.

We sent the flow chart to friends for comments and suggestions. Particularly useful criticisms came from Edward Lambe, of the State University of New York at Stony Brook, and Kenneth Ford, of the University of California, Irvine. Students within the project also suggested improvements

<u>Implementation</u>

After a brief time together working on the dialogue we returned to our respective institutions and proceeded to implement and use the dialogue on local timesharing facilities.

At the University of Michigan the dialogue was implemented in an existing FORTRAN-based conversational computer language, FOIL, developed by Karl Zinn and others at Michigan and running under the Michigan Timesharing System for the IBM 360/67. This language has since been superceded and the program will be rewritten. The original FOIL version is still in use.

The development of the dialogue as a computer program at the University of California, Irvine proceeded differently. The change in computer facilities at Irvine provided an XDS SIGMA 7, with little directly applicable software. Hence, development had to proceed in two parallel directions, generating facilities for student dialogues and developing the dialogue itself. The language facilities were developed as quickly as possible for the energy conservation program so as to allow easy extension to the electromagnetic simulation dialogue mentioned above. The dialogue facilities were developed as SIGMA 7 assembly language macros "procedures," making it easy to extend and modify the language for new uses. The macros were oriented toward professors and secretaries who are not experienced programmers. A current description of this system, with examples of usage, is available; it has proved to be flexible to changing needs, and is now being used by others also.

The secretary helped greatly in preparing the dialogue. Those acquainted with computer dialogues will realize that even an elementary dialogue entails a vast amount of typing. Experienced typists should do this typing. Hence we taught the secretary to type at the terminal, <u>directly</u> from the flow chart, the macros which constitute the final program. Only a short amount of instruction was necessary. The secretary cannot handle all details, and she was instructed to enter a row of asterisks when she was uncertain about what to type. Several secretaries at Irvine have been successfully trained in this procedure! The students who worked on the program after could easily recognize points marked by the secretary for further editing. The secretary worked at the terminal typing directly into a disk file; no cards were punched. The normal editing facilities of the computer were used to modify the program, by both the secretary and the student programmer.

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The first running version of the dialogue was available in January. This program was informally tested within the project and by colleagues in the physics department, whose useful suggestions we were able to incorporate. It was used with 150 science and engineering students at University of California, Irvine, in the first quarter of a five quarter introductory course. It was also used by a group of University of California, Berkeley students in a similar class taught by Richard Ballard, through the University of California tie-line facilities. A section of student use follows; student inputs follow the question marks at the start of the line.

```
TO BE SURE THAT WE MEAN THE SAME THING BY
"LAWS OF MOTION" ENTER THE EQUATION
OF MOTION OF A ONE-DIMENSIONAL SIMPLE
HARMONIC OSCILLATOR. (USE M FOR MASS,
X FOR POSITION, A FOR ACCELERATION, AND
K FOR SPRING CONSTANT.)

?F=MA

PLEASE ENTER THE EQUATION WITH THE
FORCE FOR THE HARMONIC OSCILLATOR

?F=-KX

THE EQUATION OF MOTION SHOULD
CONTAIN THE MASS M
TRY AGAIN TO ENTER THE EQUATION
OF MOTION FOR THE OSCILLATOR

?MA=KX

WATCH THE SIGN ON THE FORCE
TRY AGAIN.

?MA=-KX

YOUR RESULTS SEEM RIGHT
A USUAL FORM FOR HARMONIC OSCILLATOR EQUATION
OF MOTION IS M*A=-K*X.

NOW CONSIDER ANY ONE-DIMENSIONAL SYSTEM,
NOT NECESSARILY AN OSCILLATOR.

LET'S SEE IF WE CAN FIND A CONSERVED
QUANTITY BY "PLAYING" WITH THE EQUATIONS
OF MOTION.  IF WE MANIPULATE THE
EQUATION, M*DV/DT = F, UNTIL WE HAVE
TRANSFORMED IT INTO THE FORM

     D/DT (SOMETHING) = 0,

THEN "SOMETHING" IS THE CONSERVED QUANTITY
WE ARE SEEKING....!
DO YOU WANT TO BEGIN BY MODIFYING THE
EQUATION OF MOTION, OR BEGIN WITH SOME OTHER
QUANTITY?

?LETS MODIFY THE EQUATIONS OF MOTION

WHAT OPERATIONS DO YOU WISH TO PERFORM?
MULTIPLY BOTH SIDES BY THE SAME QUANTITY?
ADD THE SAME QUANTITY TO BOTH SIDES?
INTEGRATE? SOMETHING ELSE? IT MIGHT BE
FUN TO EXPLORE THESE POSSIBILITIES WITH
PENCIL AND PAPER. YOU MIGHT EVEN BE ABLE
TO ANTICIPATE WHERE WE ARE GOING....

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<u>Feedback</u>

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Feedback

Two types of feedback were obtained at Irvine, using questionnaires and selective storage of student responses on the disk. The questionnaire showed that the average time at the terminal was 58 minutes; about 15 or 20 minutes is required by a knowledgeab_e student. Most students completed the material in one section (the dialogue offered a restart facility if the student did not complete the program). The students could use either Model 33 teletypes or Datapoint 3300 alphanumeric CRT. Students preferred the Model 33 over the Datapoint, because the previous responses were often useful to them, and they were only available in the hardcopy printing of the Model 33. (Neither terminal is ideal for student use.) We also queried students on a stylistic aspect of the program. We chose the grammatical first person in addressing for the computer to use students. Some of our consultants objectsd, but student response was overwhelmingly favorable toward the first person style. Perhaps it alleviates the feeling that computers are at best impersonal; such a style may tend to humanize the computer. In spite of the problems to be mentioned next, two-thirds of the students who used the program claimed to enjoy it.

Some difficulties quickly developed with our new programming system, and it was not surprising that thev showed up in the student survey. Our testing had proceeded with only one user; when many students were simultaneously using the system, conflicts not provided for arose in use of the files. Some users were bounced out of the program, or received unintelligible error messages. Some students complained that the questions were vague or hard, and some also complained, sometimes justifiably, that the computer did not accept correct answers. The fast speed on some Datapoints (run at 1200 baud) which presented information faster than the student could read caused another problem.

Another very useful form of feedback was obtained internally in the program. When the student types in a reply, the program attempts to analyze the answer, looking for both right and identifiable wrong responses. In some cases it can find none of these expected responses. In about 40 places we inserted instructions for saving the student response in a special disk file, if we failed to analyze the response. Several thousand such responses were saved and we examined them daily. They indicated where we were missing correct responses, wrong responses we should have responded to, the weak places in the program, and ways of using the system that we had not contemplated.

<u>Student Response Information</u>

Even in this first Irvine version we did a respectable job in matching student responses; the number of places where we failed to analyze a reasonable student input--either a correct or incorrect response--is smaller than we would have predicted. Certainly there were such places, but for many questions we anticipated most of the responses.

It was comforting to note some "convergence" in the unanalyzed responses stored on the disk. As the week progressed we found fewer and fewer new corrections needed. The difference was sufficient as the week progressed to suggest that the program will soon reach the stage where we will be able to analyze almost any reasonable <u>student</u> response from students at this level, although our relatively crude matching techniques cannot analyze all possible responses. However, additional experiences are needed with students of diverse background.

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Student responses indicated a number of weak points in the program. Some of these were simply programming errors on our part. In one place, for example, we look for a "no" response but unfortunately the number 0 (zero) had been typed in our program instead of the letter O. We received vast numbers of no's listed as unanalyzed! (In the new version we always look for both.) This is a trivial error that would be difficult to spot without student feedback.

Probably the weakest section was where we introduced and used potential energy. Many students noted that we went too rapidly there.

Nor did we give students enough assistance in calculating potential energy for particular forces. A number of people arrived at this point not knowing how to make the calculation, perhaps because calculus was still a new tool for them.

Calculus notation was another problem. This may be a particular problem at Irvine, but it may be more widespread. The calculus course uses two notations for derivatives which we almost never use in physics! They indicate derivatives by a prime, or by writing a big "D," avoiding the "(d/dt)" and the dot notation common in physics. Although the "d/dt" notation was employed in the course, a number of people used the alternate notations, particularly when asked to differentiate F x G.

The responses show that a few students do not use the program as a dialogue at all, but simply use it as an information source, much the same way that students would use a book. These students, 5% of the users, either enter no response at all for question after question, or enter garbage. <u>Should</u> we worry about such a student? He is not using the program to maximum educational advantage, but he is probably no worse off and perhaps better off than if he were reading the same material in a text; at least he is sent into various remedial branches which he would not have seen in a standard text, and he is "paced" through the proof.

Using the feedback mentioned above, particularly the selective disk storage of responses, we have prepared a second version of the conservation dialogue for the SIGMA 7. The dialogue is available in flow chart and program form for those who wish to implement it elsewhere. While we would not claim any degree of perfection in its present form, the program was considerably improved by the sizable student feedback.

Potential users should recognize the limitations in the present program. Only one proof is possible, a proof which starts with the laws of motion, multiplies both sides by v, and writes everything as d/dt (something) = 0. A flexible program should follow the students' whims, at least to some extent. We have not followed all the branches we can contemplate in the program; some we hope to add in later versions. No computer program could allow <u>all</u> the possibilities, with present day technologies and know-how. But we hope that the conversation would encourage most students to take some steps themselves, and thus to develop the analytical abilities necessary for future physics progress.

Another limitation in a computer dialogue is our inability to recognize all correct responses. Recognition is particularly difficult

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if, as here, we restrict the student as little as possible with regard to possible input. Most inputs are free-form, with no directions about typing; even with formulas, we adapt the program internally to accept the various notations the students may use. Since we cannot recognize all correct responses, modest comments to students are in order when we have not recognized the response; it is dangerous in this environment to tell the student he is wrong. Hence we use comments which emphasize our limitations within the program as well as the fact that he has not put in what we expected. It should be emphasized that every implementation, in a different language facility, is bound to differ in its capabilities, and even possibly tactics, for recognizing student responses. Thus although the initial versions at Ann Arbor and Irvine were very similar, since they were both based on the flow chart, the student would not necessarily receive identical responses for identical inputs, because of different tactics of string matching to identify the critical components of the input.

We are eager to talk with people who want to implement this dialogue on other systems or use it with other groups of students besides those we have worked with. The detailed flow-chart is available on request.