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ABSTRACT

A description of the first two quarters of the beginning physics course at the University of California at Irvine is given. Lectures, films, student-computer dialogues and weekly assignment sheets dealing with special problems are used with much student choice allowed. Computer dialogues are used for proof learning, remedial mathematics, and simulation of physical systems. The general thesis is that the computer is a new but rapidly developing tool in instruction, a tool which has a selective potential for allowing different students to learn in different ways. (RB)

THE COMPUTER IN A RESPONSIVE LEARNING ENVIRONMENT--LET A THOUSAND FLOWERS BLOOM

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My tactics in my brief time will be as follows: First, like Martin Luther, I will tell you my basic theses. Second, I will illustrate them by describing a course taught the past three years, and finally I will briefly restate my position.

Thesis I: Different students learn in different ways.

Most teachers would agree, but practically all courses seem to ignore student differences. Most courses are rigidly structured, with only one path to success and only one set of learning materials. An environment truly responsive to students must have a variety of materials and techniques for learning.

Thesis II: We are only beginning the task of learning how to use computers in education.

I worry greatly about teachers who feel that they already know all the answers. We have a long way to go, and theoretical analysis will not tell us how to employ computers effectively. Hence we want to maintain flexibility, and we should be prepared for long years of trial and error while using computers in learning.

Thesis III: Useful ways to involve computers in teaching may depend on subject matter involved.

What is highly effective in physics may turn out to be useless for literature. This is obvious with computational uses, which are tailored for a specific need. It is perhaps less obvious with other types of usage. While we may find techniques which transcend subject matter boundaries, we will continue to need specific techniques for individual areas.

Thesis IV: It is wise to retain all usage modes for computers in every learning situation.

Computational, tutorial, simulatorial, managerial, and other modes as yet unnamed may all prove to be of great importance in education. Further, in view of Thesis III, a mode worthless in one discipline may be valuable in another area.

Thesis V: We should continue to develop ways of learning independent of computers.

Some areas and some students may profit from other techniques. Many powerful learning tools exist. The film can be used interactively with computers as a very effective learning medium. Furthermore, in some areas, nothing competes in teaching effectiveness with a student's experience in working problems. Thus, I am not in sympathy with the "whole course" approach to computers in education, where the computer becomes the sole medium. Today we don't know enough to use computers exclusively, and we may never want to.

Thesis VI: The test of all learning is with students--does the material, computer or otherwise, lead to some type of learning for some students?

All educational materials need to be widely used and continually modified on the basis of students' experience.

So much for my theses, which I now hope to illustrate. The course I am about to describe is only a first approach to these ideas. It comprises the first two quarters of the five quarter beginning science and engineering majors' physics course at Irvine. It is, like much else in educational computer usage, an early endeavor, one that I suspect will seem crude when we finally learn how to use computers effectively. The average enrollment has been 160 students.

At the beginning the student is given 20 weekly assignment sheets. Each sheet specifies the subject area covered and the learning devices and modes available for that topic. A typical weekly sheet is shown at the end of the paper. The course has a text (prepared at Irvine), and each week's assignment suggests something to study from the text and from references. Often The Feynman Lectures are referenced to go along with the week's assignment, and also references are made to books at other levels, to accommodate the variety of students.

This course, like many physics courses, is oriented toward the problems. Assignments contain both required problems and optional problems. The computational aspects of using the computer make themselves felt here; some of the problems can be handled only by means of the computer. The overall effect of the computation mode on the course is tremendous, affecting the type and level of material the student is capable of dealing with. Thus even the beginning student can immediately start using the laws of motion as differential equations and can study the behavior of many physical systems. I will not describe this aspect further as I have already done so a number of times.

Films are used in three ways. First, we have two loop boxes, which show a loop on a rear screen projection system each time a button is pressed. Films in these boxes appropriate to the course are announced on the weekly assignment sheet. One "lecture" period per week is used for long films. These films do not necessarily tie closely with the material of the week, but are often motivational. Finally, short films are occasionally used in lecture when they fit in dynamically with what is happening.

The student is encouraged to think of the two lectures each week as only one of the learning devices in the course; his attendance presumably depends on how effective he finds the lecture as an aid to working the problems. (Most students come to most lectures.) We do not believe, from querying our students, that students are willing to give up lectures entirely at present. Whether or not they are effective learning devices, students still want them.

The aspect I will discuss in most detail is the student-computer conversation, the dialogs, available continuously during the quarter. We have wondered about where within physics, and with what kinds of dialogs, we could hope to get extra leverage in teaching. Therefore we have not tried to computerize everything, trying always to be highly selective.

One type of dialog we have stressed can be described as the interactive proof dialog. These dialogs can be used by students as replacements for, or supplements to, lectures. The main objective is to involve the student in proving the "main line", often difficult, results on which the course depends, changing these proofs from the passive experience they are for many students in lecture and reading into an active experience where the student tries to make the critical steps, first alone, then with increasing assistance. An example of a student use of a dialog from the second quarter appears at the end of this paper.

Another type of dialog is being described by Mark Monroe at this meeting. We try to assist the student with a problem he has attempted unsuccessfully. As indicated, the course is problem-oriented; week after week the students face the task of working problems difficult for them. To develop the art of working such problems is the main goal, rather than to yield any particular physical information. The student who has direct difficulty with the problem can seek out the instructor, but in a large course this may not be feasible at the moment when he needs assistance. The dialogs can, hopefully, aid him. The easiest time to write such problem assistance dialogs is just after the problem has been assigned in class.

A third use of dialogs is for remedial mathematical assistance. The mathematical limitations of students often present a major pedagogical problem. Thus when we want to use complex numbers, we are often hindered by the very mixed background of the class. Furthermore those who have had exposure may need review. One doesn't know whether to lecture, and bore half the class, or assign reading which might not match the level of some. The diagnostic-remedial dialog such as our complex number dialog tries to determine what the student doesn't know, and then it assists him.

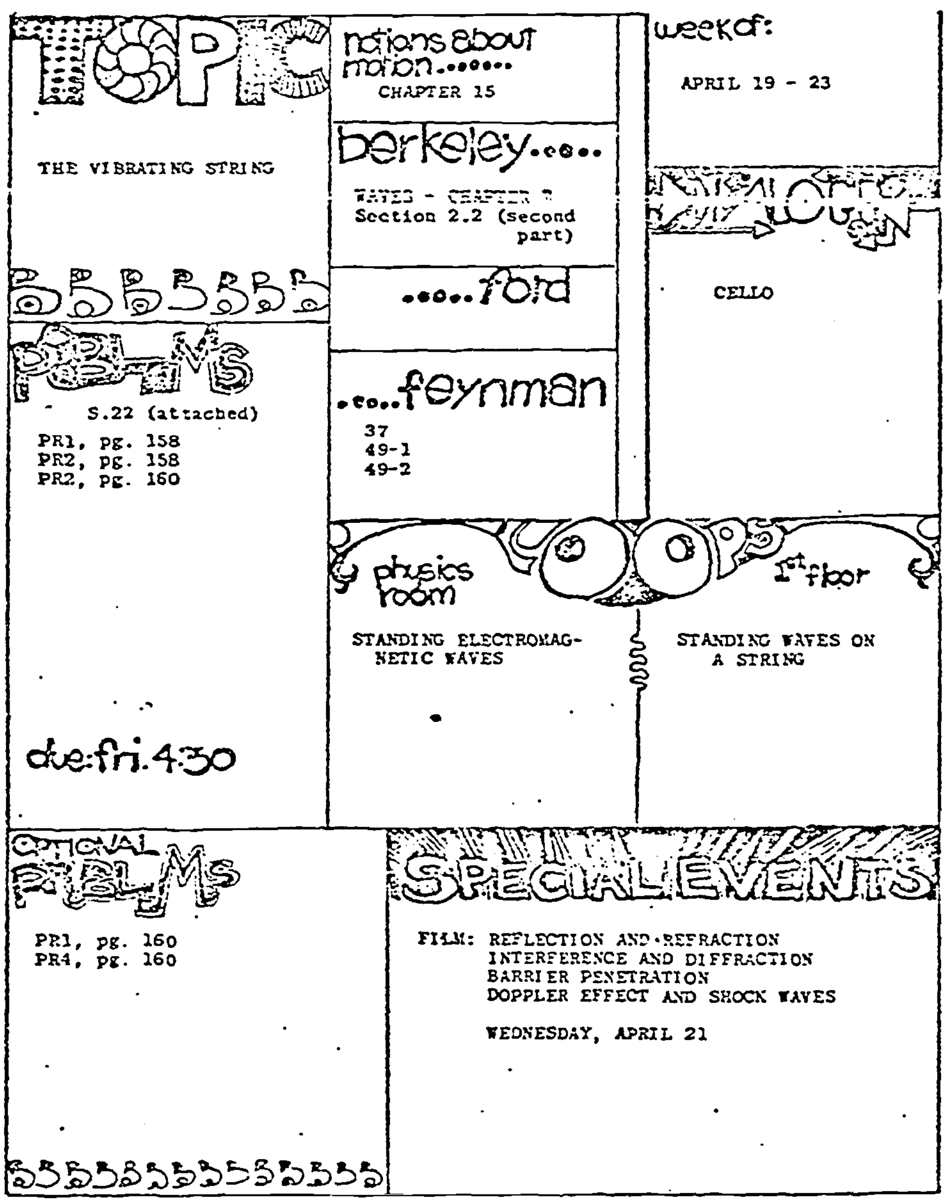
The fourth type of dialog used in the course is a simulation of a physical system; this year we have had two examples. One was a simulation of a lunar landing, from friends at Berkeley (Steve Derenzo and Noah Sherman). Knowledge about motion at constant acceleration is sufficient to provide a successful landing. Variants of this program are common. A second simulation is, from a pedagogical point of view, more ambitious because it attempts to teach, through a measurement-type discovery procedure, an important property of waves, the travelling

pattern idea. It was developed jointly by myself and John Robson of the University of Arizona. A small part with student output underlined appears at the end of this paper.

Dialogs when first written, even by the best of instructors, often turn out to be poor; none of us is good enough to anticipate all the right responses, all the reasonable wrong responses we should respond to, etc. So as the student is using the dialog, we file responses we cannot analyze and other information about his progress which may help us to improve the dialog for future students. Thus gradually we make the dialogs more effective through extensive use with students and through successive revisions.

Since the dialogs are not required--like the lectures, they are used by students who they feel they help with problems--we also want to find which students are using which dialogs, and whether this use affects their performance. In spite of the large effort required one must always remember that the dialog might turn out to be useless, so that no amount of improvement through usage will produce a viable teaching program. Edwin Taylor at MIT has suggested that one way of telling what is useful is by letting students decide. Hence our system records dialog usage.

This is just one course. I hope that many other courses in physics, and in many other areas which use computers, will be developed. I believe that we <u>should</u> have a thousand flowers blooming. I realize that many of them, probably even some of my <u>own</u>, will be ugly. The botanist knows that not all flowers end up in elegant, cultivated gardens. Only through careful breeding over many years can we find the desirable types. And in our responsive learning environment, an environment responsive to student needs, many flowers besides the computer flowers will also be blooming.



GET DIALOG
 - PROGRAM NAME? CELLO

PLEASE TYPE AN IDENTIFICATION
- 7 CHARACTERS OR LESS - - - ALFRED

THAT IDENTIFICATION HAS BEEN USED BEFORE.
WAS IT BY YOU?

?NO

THEN PLEASE INPUT ANOTHER IDENTIFICATION.
- 7 CHARACTERS OR LESS - - - AMB

FIRST, LET'S TALK SOME ABOUT THE
WAVE EQUATION IN ONE DIMENSION.
WHAT KIND OF EQUATION IS THE WAVE
EQUATION?

?A LINEAR DIFFERENTIAL EQUATION

WHAT KIND OF DIFFERENTIAL EQUATION?

?PARTIAL

YES, IT'S A PARTIAL DIFFERENTIAL
EQUATION. GOOD.
WHAT IS THE ORDER OF THE DERIVATIVE
WITH RESPECT TO POSITION? IS IT A
FIRST DERIVATIVE, OR WHAT?

?SECOND

RIGHT. IT IS A SECOND DERIVATIVE.
WHAT ABOUT THE ORDER OF THE TIME DERIVATIVE?

?2ND ALSO

YES, IT IS ALSO A SECOND DERIVATIVE.
IN ADDITION TO DERIVATIVES, THE WAVE
EQUATION CONTAINS ANOTHER PHYSICAL
QUANTITY ASSOCIATED WITH WAVES.
WHAT IS IT?

?FREQUENCY?

THIS IS A WAVE PROPERTY, BUT ONLY
FOR CERTAIN TYPES OF WAVES. WHAT
OTHER QUANTITY OCCURS IN THE WAVE
EQUATION?

?THE VELOCITY OF THE WAVE

YES, THE WAVE EQUATION CONTAINS
THE WAVE VELOCITY.

WE WANT SOLUTIONS OF THE WAVE EQUATION
FOR A STRING WITH FIXED ENDS, FIRST FOR
MOTIONS IN WHICH ALL PARTS OF THE STRING
MOVE WITH THE SAME FREQUENCY. SO
WHAT SHOULD WE ASSUME FOR THE FUNCTIONAL
DEPENDENCE OF THE SOLUTION ON TIME?

?SIN OR COS

THERE ARE THREE POSSIBILITIES HERE FOR
THE TIME DEPENDENT PART OF THE SOLUTION,
 SIN WT, COS WT, AND EXP(IWT)

THE 'NORMAL MODE' SOLUTIONS OF THE
WAVE EQUATION ARE OF THE FORM
 A(X) EXP(IWT) OR A(X) COS WT OR A(X) SIN WT
THE POSITION X SHOWS WHERE WE ARE ALONG THE STRING.
YOU SHOULD CONTRAST THIS
WITH THE TWO-BODY NORMAL MODE SOLUTION,
THE FUNCTIONS REPRESENTING THE MOTION OF
THE TWO MASSES ARE:
 X1=A EXP(IWT) AND X2=B EXP(IWT)

WHAT IS THE PHYSICAL MEANING OF A(X)

?THE AMPLITUDE

YES.....
ALL POINTS ON THE STRING OSCILLATE WITH THE
SAME FREQUENCY, BUT WITH AN AMPLITUDE WHICH
VARIES WITH POSITION ALONG THE STRING.

WHAT DIFFERENTIAL EQUATION MUST BE SATISFIED BY
THE AMPLITUDE A(X)

?THE WAVE EQUATION

THE FULL EXPRESSION
 A (X) EXP(IWT)
SATISFIES THE WAVE EQUATION. WRITE THE
EQUATION A SATISFIES.

? D↑2 A / DT↑2 = - (W/V)↑2 * A

TROUBLE RECOGNIZING YOUR RESPONSE
PERHAPS WITH THE CLUMSY DERIVATIVE
NOTATION NEEDED AT A TYPEWRITER
INDICATE THE FIRST DERIVATIVE WITH RESPECT TO
X BY A' AND THE SECOND DERIVATIVE BY
 A''

? A'' = -(W/V)↑2 A

SO A'' + (W/V)↑2 A = 0

THIS EQUATION MAY WELL LOOK FAMILIAR
TO YOU. WITHOUT GOING INTO PRECISE
DETAILS, DESCRIBE THE SOLUTIONS A(X).

?SINS AND COS

YES.
COMPLETE THIS SOLUTION:
 A(X)=SIN (W/V T)

POSITION -X- IS THE INDEPENDENT VARIABLE.
COMPLETE THIS SOLUTION:
 A(X)=SIN (W/V X)

FINE......
COSINES WOULD ALSO WORK.
SO THE NORMAL MODES OF OUR VIBRATING
STRING ARE OF THE FORM
 SIN(W/V X) EXP(IWT)
OR, WORKING WITH THE REAL PART,
 SIN (W/V X) .COS WT

BUT WE ARE STILL NEGLECTING PART OF THE
ORIGINAL STATEMENT OF THE PROBLEM. DO
YOU REMEMBER WHAT ASPECT OF THE
VIBRATING STRING, AS ORIGINALLY DESCRIBED
HAS NOT BEEN USED HERE YET?

?NO

IT WAS A LONG TIME AGO!

WE INITIALLY REQUIRED THAT THE ENDS BE
FIXED, NOT MOVING, AND WE HAVE NOT MADE
USE OF THIS INFORMATION.

CAN YOU SEE WHICH QUANTITY IN
OUR NORMAL MODE SOLUTION,
 SIN (W/V X) .COS WT
WILL BE RESTRICTED BY THE CONDITION
OF FIXED ENDS?

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!GET DIALOG
 -- PROGRAM NAME? ROPEGAME

THE PHYSICAL SYSTEM WE WILL EXPLORE IS
AN EXTREMELY LONG ROPE WITH A DISTURBANCE
IN IT IF YOU TELL ME A POSITION ALONG THE ROPE
AND A TIME, I WILL GIVE YOU THE DISTURBANCE,
THE DISPLACEMENT FROM EQUILIBRIUM. YOUR JOB
IS TO LEARN WHAT IS HAPPENING IN THE ROPE.

I WILL EVENTUALLY TURN THE TABLES, GIVING YOU
INFORMATION AND ASKING YOU TO PREDICT VALUES.

POSITION IS IN METERS AND TIME IN SECONDS;
DON'T ENTER UNITS.


TIME = 2          POSITION = 2          DISTURBANCE =   0
TIME = 5          POSITION = 5          DISTURBANCE =   0
TIME = 58         POSITION = 475        DISTURBANCE =   0
TIME = 0          POSITION = 0          DISTURBANCE =   0.28
TIME = -1         POSITION = -1         DISTURBANCE =   0

YOU'VE FOUND THE ACTION. KEEP GOING....

GRAPHS OR SKETCHES MIGHT BE USEFUL.
TIME = 1          POSITION = 1          DISTURBANCE =   0
TIME = 1          POSITION = 3          DISTURBANCE =   0
TIME = 1          POSITION = 5          DISTURBANCE =   0.15
TIME = 1          POSITION = 6          DISTURBANCE =   0
TIME = 1          POSITION = 3.5        DISTURBANCE =   0.08

THIS PUZZLE HAS A 'PAYOFF'. IF YOU
CAN DETERMINE HOW THIS DISTURBANCE BEHAVES,
YOU WILL UNDERSTAND AN IMPORTANT PRINCIPLE
INVOLVED IN MANY PHYSICAL SYSTEMS.
AFTER A FEW MORE MEASUREMENTS YOU CAN
TURN-THE-TABLE AND TRY TO PREDICT THE
BEHAVIOR OF THE ROPE.
TIME = 1          POSITION = 4.5        DISTURBANCE =   0.15
TIME = 0          POSITION = 5.5        DISTURBANCE =   0
TIME = 1          POSITION = 4          DISTURBANCE =   0.28
TIME = 1          POSITION = 4.75       DISTURBANCE =   0.15
TIME = 1          POSITION = 5.25       DISTURBANCE =   0.08

YOU MAY HAVE SOME IDEA OF HOW THE ROPE IS
BEHAVING. AT THIS POINT I WILL CHANGE THE
RULES OF THE GAME. FOR:
     MEASUREMENT  TYPE M
     TURN-THE-TABLES TYPE T
     LIST OF MEASUREMENTS  TYPE L
     GRAPH    TYPE G
DON'T BE DISTURBED IF YOU CAN'T TURN THE
TABLES AT FIRST--I WILL GIVE YOU OTHER CHANCES,
MEASURE? LIST? TURN? GRAPH?   G

WHAT INDEPENDENT VARIABLE DO YOU WANT FOR
YOUR GRAPH?    POSITION
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(Program continued on the next page)

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FOR WHAT VALUE OF TIME?  1
    MIN     HORIZONTAL       MAX       6
 0     MIN       VERTICAL        MAX       0.2755
-------------------------------------------+--------------------------













                                                         +
                                                     +       +



                                                                      +
                                           +




+---------------------------+--------------------------------------------+
MEASURE? LIST? TURN? GRAPH?   G

WHAT INDEPENDENT VARIABLE DO YOU WANT FOR
YOUR GRAPH?   X

FOR WHAT VALUE OF TIME?  0

NOT ENOUGH MEASUREMENTS AT THAT VALUE TO
BOTHER PLOTTING.
MEASURE? LIST? TURN? GRAPH?   M

HOW MANY MEASUREMENTS IN THIS BLOCK?  5

TIME = 2            POSITION = 7           DISTURBANCE =    0
TIME = 2            POSITION = 8           DISTURBANCE =    0.28
TIME = 2            POSITION = 9           DISTURBANCE =    0.15
TIME = 0            POSITION = 7.5         DISTURBANCE =    0
TIME = 2            POSITION = 7.5         DISTURBANCE =    0.08
MEASURE? LIST? TURN? GRAPH?   T

YOU KNOW ALREADY THAT AT T =  0 AND AT  X =  0
     THE DISTURBANCE =    0.28


AT T =   2.99  THE DISPLACEMENT IS TO BE THE SAME.
WHAT VALUE OF POSITION MAKES THIS THE CASE?

?11.9

SEEMS GOOD. LET'S TRY ANOTHER OF THE
SAME TYPE.
YOU KNOW ALREADY THAT AT T =  1 AND AT  X =  5
     THE DISTURBANCE =    0.15


AT T =   5.14  THE DISPLACEMENT IS TO BE THE SAME.
WHAT VALUE OF POSITION MAKES THIS THE CASE?

?21.6

FINE.....NOW WE'LL PLAY THE GAME A SLIGHTLY
DIFFERENT WAY.
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