

COMPUTERS IN PHYSICS INSTRUCTION

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In a rapidly growing field computers talk to students, simulate experiments, calculate and perform many special tasks. Problems remain to be solved, but if advantages are exploited and costs reduced, computers should become effective, uncomplaining tutors.

THE PHENOMENAL IMPACT of the modern digital computer on our society has not bypassed physics instruction. As early as the late 1950's and early 1960's research was going on at the Universities of Michigan and Illinois on computers in science and engineering education. Development of the field was stimulated by two conferences in 1965 at the University of California, Irvine, and the University of Washington. The reports on these conferences are basic references for anyone wishing to look further into the subject.^{1,2} The number and variety of current projects in the field is increasing rapidly, as indicated by the sections devoted to the subject at annual meetings of the American Association of Physics Teachers.

We have made a survey of computer-assisted instruction projects in physics and have explored the different ways teachers are using their machines. They are finding many applications with the computer functioning in a few fundamental roles. In the future they will, we hope, avoid the difficulties of computer instruction and exploit the unusual properties until the machine becomes a patient, effective

tutor at a cost as low as 25 cents per hour per student.

MODES OF USE

For computer-assisted instruction the machine is used in three distinct modes and also in some special ways not included in any of them. In one mode it can take the tedium out of problem solving and thus increase the effectiveness of problem solving as a way to learn physics. In a second it is programmed to "converse" with its student and thus become his "tutor." In a third mode it can simulate experiments and provide either raw data or graphical summaries of them. In special applications it can generate such things as motion pictures and circuit diagrams.

Computational mode

Problem solving is generally accepted as a successful way of learning physics, but sometimes the calculations become so difficult and time-consuming that the student loses sight of the physics involved. The efficiency and versatility of the computer can save student time and allow the assignment

of more basic and realistic problems.

An example is Alfred M. Bork's project on the principle of least action.³ As the student draws curves of displacement as a function of time for a particular physical system on a Rand tablet, the computer calculates the Lagrangian action for this curve. A Rand tablet is an input device comprising a sheet of Mylar with a grid of copper lines. Capacitive coupling to a stylus tells the computer where the stylus is touching the tablet. After the computation the computer displays the value of the action on the cathode-ray tube of the terminal. As successive curves are drawn, the computer will keep the one with the smallest action integral on the screen and show the value of the action. Without doing any actual computation, the student can approach the curve of least action. The purpose is not to replace analytic techniques but to allow the introduction of the idea of least action and variational principles at a much earlier stage in a physics course.

Conversational mode

In another mode the computer is programmed to give instruction, ask questions and react to responses through a typewriter or a cathode-ray tube as illustrated in figures 1 and 2. We call this the "conversational mode."

Computer languages use the versatility of the machine to make computer responses reasonably lifelike, approximating a conversation between the student and his tutor.

The ELIZA program developed at Massachusetts Institute of Technology permitted tutorial conversation in English between a student and either one of the MIT time-shared IBM-7094

computers. It has a sophisticated ability to recognize what the student is saying by attempting to match his input sentence to a series of patterns. The system and some impressive illustrations of its capabilities have been described by Joseph Weizenbaum.⁴

Edwin F. Taylor⁵ used ELIZA to provide automated remedial tutoring in topics on special relativity. After an initial interview with the computer, the student reads selected references on the subject and attempts to do exercises. Then he "discusses" the exercises with the computer. He is given opportunities to control the course of the conversation, as illustrated in figure 3. Taylor concludes that the experiment was successful in that the students interviewed preferred this method of exploring the topic to the lecture method. Students showed "little inclination to accept leadership in their own studies," however, and felt that "the computer was in charge of the learning process rather than they themselves."

Although this mode seems closely derived from programmed instruction, it is much more versatile and powerful because of the evaluative and decision logic of the computer. By telling the student instantly whether he is right or wrong and why, the computer provides the immediate reinforcement or correction so helpful to learning. It can be programmed to present audio-visual materials at appropriate places in a lesson. By response-dependent branching the computer can guide a student through a sequence of questions designed especially for him. It

can give him a quiz, tell him his score and branch him to appropriate study materials.

Simulation

A promising computer application is simulation of experiments. A given experimental situation is represented by an equation or set of equations programmed into the computer. After the student specifies a set of initial conditions, the computer generates data such as those the student would gather in an actual experiment. The student does not have direct access to the simulation program itself, and his objective is usually to determine these relationships from the data, just as in a real experiment, by curve plotting and data analysis.

The simulation program can be written so that the data generated by the computer include uncertainties corresponding to experimental error. Also, values of parameters can be varied from one presentation of the problem to the next by generation of random numbers within a given numerical range.

Even though a simulated experiment cannot replace the experience a student gains from handling apparatus, it can serve as an extension of the laboratory by removing, in some cases, limitations caused by cost of equipment, considerations of safety and excessive time the real experiment would take.

A possible extension of this technique is for the student to write his own programs as a study in simple programming as well as in developing

theoretical models, which he then can test with numbers. Simple languages permit students to store their own programs in the computer for future use. For example, a student can write, test and store his own data-analysis program and then use it with both real and simulated experiments.

Science Research Associates has developed a series of simulated experiments in elementary physics and chemistry. In the familiar inclined-plane experiment illustrated in figure 4, the student can specify the ramp angle and the masses of the two bodies, and the computer will provide data on the displacement of the bodies as a function of time. The student can write programs to calculate speed, frictional forces, tension in the rope, etc. He can also repeat the experiment varying ramp angle and the masses.

Films and other applications

A unique method for producing animated films uses numerical solutions of differential equations provided by the digital computer. Plots of states of the system at successive times are displayed on a cathode-ray tube and photographed on motion-picture film.⁶ An excellent example of the visualization made possible by such movies is the formulation by Abraham G. Goldberg, Harry M. Schey and Judah L. Schwartz⁷ of one-dimensional quantum-mechanical transmission and reflection phenomena. As illustrated in figure 5 it shows how a Gaussian wave packet impings on a square well or barrier.

A dramatic display of relativistic ef-



Guenter Schwarz, professor of physics and director of the Center for Research in College Instruction of Science and Mathematics at Florida State University, received a degree from the Technical University of Berlin in 1938 and a PhD from Johns Hopkins in 1942. His major field is undergraduate instruction. Other interests of Schwarz are classical music, photography, politics and counseling of young people on "freedom from fear and war."



Ora M. Kromhout, married to a physicist, is the mother of three children. She received her BA from Tulane in 1945, her MS from the University of Illinois in 1951, and is now a curriculum writer in physics at the Computer Assisted Instruction Center of Florida State. She has done research in design and development of vacuum tubes and in fiber properties. Mrs Kromhout is also a member of the Florida State Board of the League of Women Voters.



Currently professor and associate chairman of physics at Florida State, Steve Edwards devotes his research time to low-energy nuclear theory. Florida State gave him a BS in Physics and Mathematics in 1952, an MS in Physics in 1954 and the Coyle E. Moore Award for teaching in 1965. He received a PhD from Johns Hopkins in 1960. Edwards is married and has one daughter, and his hobbies include music (he is a bassoonist) and gardening.

WHICH SCRIPT PLEASE
canvec

WOULD YOU LIKE ME TO RESTATE THE PROBLEM FOR YOU.
yes

GIVEN A 4-VECTOR $V=(V_T, V_X, V_Y, V_Z)$, SHOW THAT THERE EXISTS AN INERTIAL FRAME OF REFERENCE IN WHICH V HAS ONE OF THE THREE FORMS:

1. $(A, 0, 0, 0)$
2. $(0, 0, 0, A)$
- OR 3. $(A, 0, 0, A).$

RATHER THAN DEVELOP AN ALGEBRAIC PROOF FOR A GENERAL 4-VECTOR, LET'S TAKE A LOOK AT SOME PARTICULAR 4-VECTOR AND SEE WHAT WE CAN COME UP WITH.

WOULD YOU LIKE TO CHOOSE THE COMPONENTS OF THIS VECTOR OR SHALL I.
you, please

ALL RIGHT. LET'S TAKE THE VECTOR $(5, 2, -2, 1)$.

BEFORE WE GO ON, MAKE AN 'EDUCATED GUESS' AS TO WHICH OF THE THREE SPECIAL FORMS THIS VECTOR WILL TAKE WHEN WE ARE THROUGH.
the first

OK, LET'S SEE IF YOU'RE RIGHT.
HOW ARE THE COMPONENTS OF A 4-VECTOR IN ONE FRAME OF REFERENCE RELATED TO THE CORRESPONDING COMPONENTS OF THE SAME 4-VECTOR IN ANOTHER FRAME OF REFERENCE.
the squared interval, $v_t^2 - (v_x^2 + v_y^2 + v_z^2)$, is the same

NOT PROGRAMMED, TRY ANOTHER ANSWER.
by the lorentz transformations

RIGHT.
IN ORDER TO PERFORM A LORENTZ TRANSFORMATION ON THE COMPONENTS OF THIS 4-VECTOR, WE SHOULD DECIDE ON WHAT DIRECTION TO PICK FOR THE RELATIVE VELOCITY BETWEEN THE LAB FRAME AND THE NEW FRAME (CALL THIS VELOCITY BETA OR B). WHAT DIRECTION WOULD YOU PROPOSE.
in the direction of r

SORRY, BUT I CANNOT YET INTERPRET YOUR RESPONSE. SO THAT WE MAY CONTINUE, LET ME PROPOSE A DIRECTION PARALLEL TO THE SPATIAL PART OF THE ORIGINAL 4-VECTOR. YOU ARE PROBABLY NOT

FAMILIAR WITH THE FORM OF THE LORENTZ TRANSFORMATION EQUATIONS WHEN THE DIRECTION OF MOTION IS NOT ALONG ONE OF THE COORDINATE AXES. THEREFORE, LET'S SIMPLIFY THE PROBLEM FIRST. ROTATE THE SPACE AXES UNTIL THE Z -AXIS OF THE ROTATED COORDINATE SYSTEM LIES ALONG THE SPATIAL PART OF V . PLEASE TYPE IN THE COMPONENTS OF V IN THE ROTATED COORDINATE SYSTEM.
 $(5, 0, 0, 3)$

RIGHT.
NOW PERFORM A LORENTZ TRANSFORMATION ALONG THE NEW Z AXIS. HOW WILL MOTION IN THIS DIRECTION AFFECT THE COMPONENTS OF THE 4-VECTOR ALONG THE NEW X AND Y DIRECTIONS.
it will not

THAT IS CORRECT.
NEXT LOOK AT THE T AND NEW Z COMPONENTS. THERE IS A VALUE OF THE VELOCITY, B , FOR WHICH ONE OF THESE COMPONENTS VANISHES. WHAT IS THIS VALUE OF B .
 $3/5$

GOOD.
IN FACT WITH $B = .6$
THE TRANSFORMED VECTOR V NOW HAS THE COMPONENTS:

$$(4.0, 0, 0, 0)$$

THE ORIGINAL VECTOR HAS NOW BEEN TRANSFORMED TO ONE OF THE STANDARD FORMS, NAMELY:

$$(A, 0, 0, 0)$$

HENCE YOUR ORIGINAL GUESS WAS CORRECT. CONGRATULATIONS. NOW THAT YOU HAVE WORKED THROUGH AN EXAMPLE IN DETAIL, DO YOU SEE HOW A SIMILAR PROCEDURE COULD BE APPLIED TO AN ARBITRARY 4-VECTOR.
yes

THIS IS THE EXTENT OF THE CURRENT PROGRAMING.

WOULD YOU LIKE TO TRY ANOTHER VECTOR BEFORE YOU GO.
why not

THANK YOU FOR YOUR COOPERATION. ANY COMMENTS YOU MAY HAVE ABOUT YOUR INTERACTION WITH THIS PROGRAM WILL GREATLY ASSIST US IN IMPROVING ITS CONTENTS.
the question about which direction to choose is hard to answer properly.

THANK YOU AGAIN. GOODBYE.

CONVERSATION WITH COMPUTER, typical of MIT ELIZA program. Computer speaks in capital letters; student in lower case. Towards the end computer misreads "why not" (reference 5). —FIG. 3

fects has been developed by Schwartz and Taylor⁸ of MIT. The operator can control the acceleration of an imaginary "rocket car" by touching his light pen to the "accelerate" control line on a cathode-ray screen and observe various relativistic effects such as the apparent shape of the "telephone poles" lining the road (figure 6).

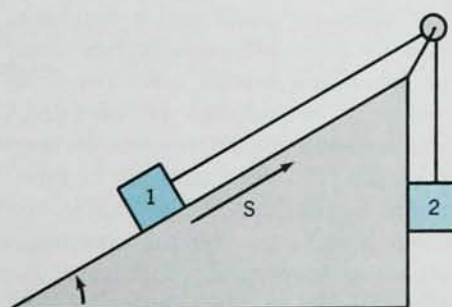
Other instructional computer uses are in on-line control of experiments in the advanced laboratory and the use of large memories as data banks with rapid access through efficient information-retrieval systems. In a computer-based calculus course that is currently being developed⁹ students use the computer to calculate limits and do epsilon-delta continuity calculations numerically. Thus they actually experience what convergence means.

SURVEY OF PROJECTS

We have surveyed representative computer-assisted-instruction projects in physics and offer brief descriptions of them in the table on pages 46 and 47. The tabulation does not, of

course, include all projects. For instance, more projects than the table indicates use small computers such as the IBM-1130. They may be the best approach for many schools. There are also high-school projects, for example at the Thatcher School in California, Polytechnic Institute of Brooklyn and the Florida State University Intermediate Science Curriculum Study program.^{10,11}

Instructional use of the computer requires languages that can be used



INCLINED-PLANE DIAGRAM presented to student in simulation of experiment. He is asked to specify ramp angle and masses of two bodies; computer provides relevant data. —FIG. 4

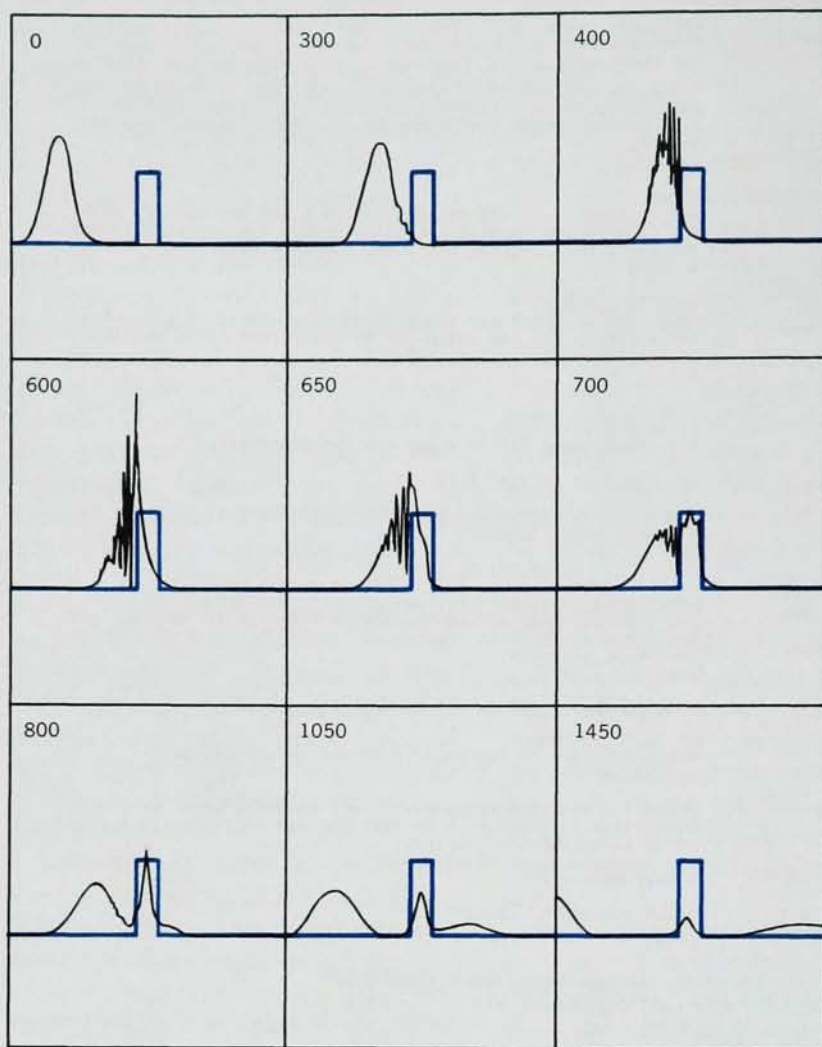
by the course author with minimal training.¹² The variety shown in the table reflects the adaptation of languages to particular computers and modes of use. Some of these languages require no training of the student who uses the program, and most can be learned in a very short time compared with standard programming languages.

SPECIAL CAPABILITIES

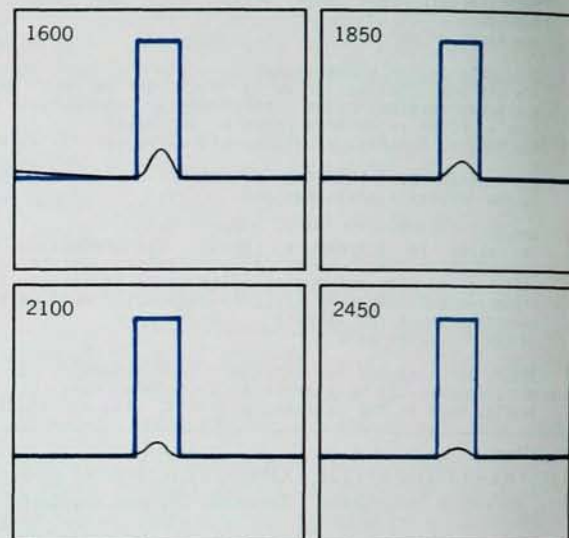
Properties that are unique to computers lead to the introduction of some quite new teaching methods. Simple languages and time-sharing terminals, for example, are making the computer almost a universal tool on some campuses. Special materials are under development, and some courses are given entirely with computer instruction. An important by-product of applications is useful information about the performance of students—both as individuals and as groups.

Computational applications

Dartmouth College, in setting up its time-sharing computer system,¹³ decid-



GAUSSIAN WAVE PACKET SCATTERING from square barrier. Time in arbitrary units is indicated by number in each frame. Frames 1600 to 2450 show in detail decay of resonant state that is developed during scattering (reference 7). —FIG. 5



ed to make its use so convenient to students and faculty across the campus that it would become an essential and habitual part of the educational process. The success of this project arises largely from the ease with which the system can be used and from the development of a simple language (BASIC), a combination of elementary algebra and almost ordinary English. About 80% of Dartmouth freshmen learn to write and debug their own programs in two one-hour lectures.

Second-year physics students have used the system to explore the bound states of a particle in a one-dimensional square-well potential in coordinate and momentum representations.¹⁴ The terminal types out a request for a trial energy and the symmetry of the function. The student supplies this information, and then the program numerically integrates the Schrödinger equation and, if requested, plots the function on the terminal typewriter. By successive trials of input energies, the student finds the eigenvalue and can have the computer plot the eigenfunction. These results are then used for further explorations

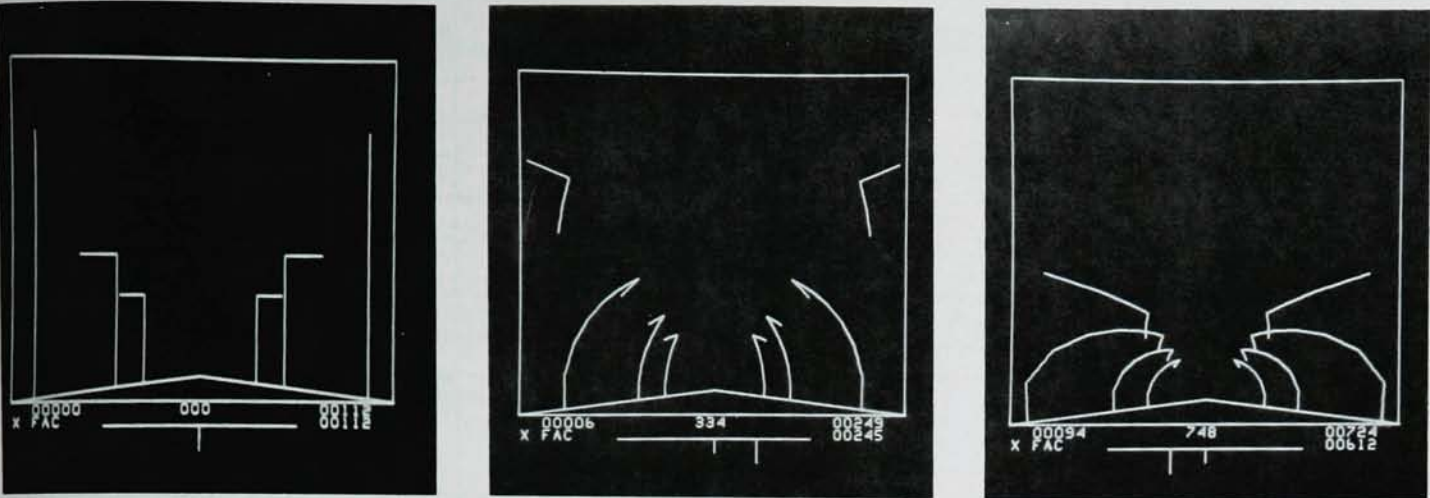
in other programs. Use of the Dartmouth computer in physics instruction is expected to increase, perhaps in the direction of a freshman laboratory organized around the computer.¹³

During the summer of 1968 the Commission on College Physics sponsored a workshop at Irvine. Materials developed could be used with a number of different languages and computers. One monograph titled "Introductory Computer-Based Mechanics: A One-Week Sample Course," edited by Ronald Blum, has been published by the commission.¹⁵ It consists of a student manual and a teacher's guide for three successive lectures and one laboratory session. No previous knowledge of calculus or restoring-force laws is required, but one lecture on simple first-order methods of integration is provided. The student is shown how to convert the equations into computer-program statements, finally arriving at the solution of the harmonic-oscillator problem. This section is available in four languages: BASIC, FORTRAN, JOSS and PL/I. A second monograph will cover other results from the cooperative session.

Conversational applications

At the Florida State University computer-assisted-instruction center, a complete computer-guided one-term course in introductory noncalculus physics has been given, for credit, to two groups of nonscience freshmen.¹⁶ There were no "live" instructors or formal class sessions. Students came to the center by individual appointment and proceeded through the 29 lessons at their own rates. The lessons consisted of audio-tape lectures illustrated by film-loop demonstrations and some of the Physical Science Study Committee movies. An IBM-1500 computer system was used to direct the student through the course, quiz him on assigned text reading before letting him start each lesson, ask him questions on the materials covered in each lecture and movie immediately after its presentation, and keep track of his answers and performance throughout the course.

One of the by-products of using the computer in this mode is the collection and analysis of detailed data on the student's performance. Objective



RELATIVISTIC EFFECTS shown on still frames from a computer-made film (reference 8). Shapes and orientations of telephone poles have seemingly changed at different speeds of imaginary rocket car. Left-hand number below frame gives number of poles passed; center number gives value of v/c ; upper right-hand number gives time on adjacent road clock in stationary road frame; lower number gives time on clock in car as seen from the road. Scale below v/c value is "accelerate" control line. Letters are student controls: touching X with light pen causes car to restart from beginning; F freezes motion; A causes car to accelerate at rate set on center scale, and C causes it to coast at constant speed. —FIG. 6

THE CENTER COURSE P107			ITEM ANALYSIS SUMMARY										DATE 04-16-68				
IDENTIFIER	N	ID	N(I)	P.C.	AVG LAT	S.D.	ID	N(I)	P.C.	AVG LAT	S.D.	ID	N(I)	P.C.	AVG LAT	S.D.	
20C01L	23	UU	23	100.0	6.84	9.930											
20C02C	23	C1	22	95.6	12.71	8.174		1	4.3	67.60	0.006						
20C03C	22	C1 W2	17 1	77.2 4.5	13.93 23.40	17.918 0.006	UU	1	4.5	30.90	0.006	W1	3	13.6	14.10	8.774	
20C04C	22	C1	22	100.0	11.80	8.659											
20C05C	22	C1 W3	11 2	50.0 9.0	30.43 29.40	12.828 5.400	UU	1	4.5	18.40	0.004	W2	8	36.3	30.99	15.071	
20C06C	22	C1 W3	18 1	81.8 4.5	12.28 27.40	8.213 0.003	UU	1	4.5	34.80	0.010	W2	2	9.0	8.05	0.050	
20C07C	22	C1	15	68.1	9.48	5.184	W2	5	22.7	7.07	3.105	W3	2	9.0	16.30	4.099	
20C08C	22	C1	18	81.8	21.91	13.999	W1	4	18.1	17.20	5.117						
20C09C	22	C1	21	95.4	11.45	7.737	W1	1	4.5	6.40	0.001						
20C10C	22	C1	21	95.4	21.13	21.493	W3	1	4.5	12.00	0.000						
20C10R	22	UU	22	100.0	14.94	14.690											
21A01C	29	C1	28	96.5	14.38	15.499	W2	1	3.4	10.00	0.000						
21A02C	29	C1	22	75.8	18.77	16.715	W1	7	24.1	34.11	21.440						
21A03C	29	C1	22	75.8	15.74	20.102	UU	1	3.4	26.50	0.000	W2	6	20.6	12.56	8.235	
21A04C	29	C1	24	82.7	17.75	15.464	W2	5	17.2	22.41	12.330						
21B01C	22	C1	15	68.1	20.58	13.968	W2	6	27.2	15.79	6.893	W3	1	4.5	13.90	0.001	
21B01F	22	UU	22	100.0	3.74	2.336											
21B02C	22	C1 W3	9 1	40.9 4.5	44.96 13.90	14.048 0.001	W1	11	50.0	32.75	14.188	W2	1	4.5	41.30	0.008	
21B03C	22	C1	16	72.7	10.81	6.053	W2	5	22.7	24.78	12.766	W3	1	4.5	8.50	0.000	
21B04Q	22	C1	15	68.1	38.52	23.421	UU	7	31.8	44.41	26.020						

STUDENT ANALYSIS. Partial printout of program from Florida State Physics 107 course shows total class performance for each question. Meanings of column headings are as follows: IDENTIFIER designates each specific question to which a student is asked to reply. N is total number of students who answered the question; ID describes type of response (C1 is correct answer; W_n designates recognized wrong answers; UU is an unrecognized response); N(1) is the number of students who chose the response identified in the previous column; P.C. represents N(1)/N in per cent; AVG LAT is the "average latency" or average time in seconds taken by students to make that response; S.D. is standard deviation of average latency. —FIG. 7

quantitative information of this kind has not been available to the instructor in the past. It can be used to improve overall strategies of teaching as well as help with the evaluation and revision of specific questions. For example, one can conclude from the typical printout shown in figure 7 that question 20C04C provided no discrimination because all students answered correctly whereas question 21B02C may be too difficult since only 40.9% gave the correct answer on first pass.

Students interviewed at the end of the course for the most part liked the method, particularly the freedom to arrange the hours for their lessons and to set their own paces. On the average they performed at least as well on the same examinations as did their "classmates" in the conventional lecture section. Several students felt, however, that this presentation is best suited to the student who is good at "digging things out for himself." They emphasized the need for capable and easily available proctors to help with operational problems as well as to answer physics questions.

Simulation applications

Robert E. Lindsay has told us of an intriguing example of simulation. It is the set of electricity and magnetism problems developed at the Thomas J. Watson Research Center of International Business Machines. Models of classical experiments are being developed, depending heavily on the graphic capability of the IBM-1500 system and its cathode-ray-tube terminal. Student interaction is accomplished entirely with the light pen although use of the keyboard and combination interaction are planned. For example the student might wish to perform the experiment "Multiloop DC Network." The screen displays a diagram of the network, which includes a dc source, five resistors, and three switches as shown in figure 8. It also displays a diagram of a multimeter with the words AMP and VOLT, which can be made to serve as an ammeter and voltmeter by touching the appropriate word with the light pen. In the lower left-hand corner of the screen are the words DATA, SHOW, HELP, ANSWER, and CIRCUIT.

When the student is ready to perform the experiment, he touches CIRCUIT. To determine the values of the resistances, which are randomly generated for each new experiment, he must connect the meter into the cir-

Representative Computer-Assisted Instruction Projects In Physics

NOTES FOR TABLE

* A = precollege
B = introductory college, noncalculus
C = introductory college, calculus
D = higher courses

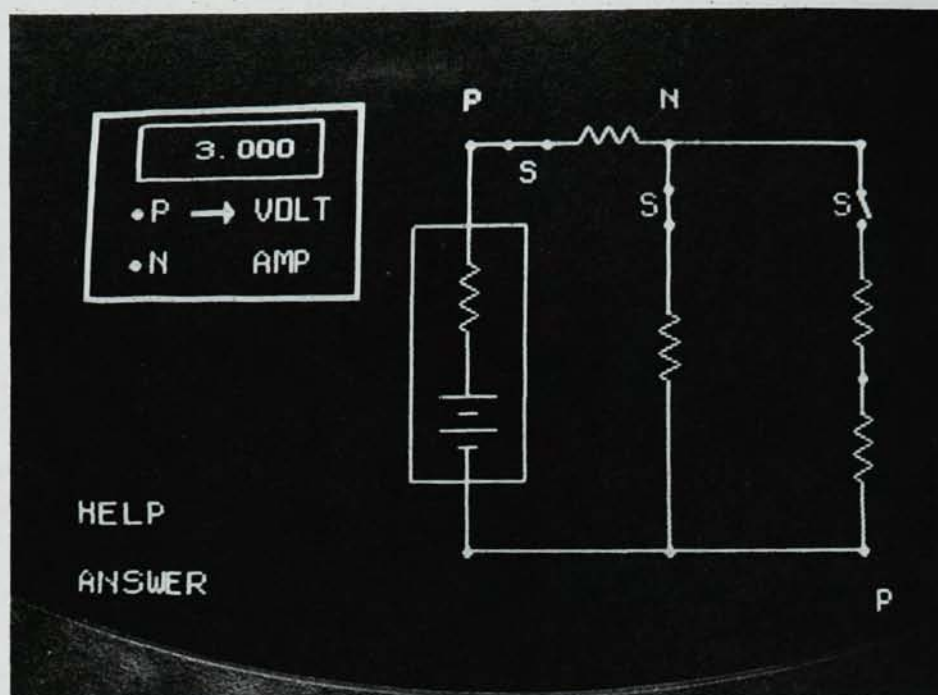
† Comp = computational
Conv = conversational
Sim = simulation

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¶ Seattle Conference on New Instructional Materials in Physics (1965).

Project	Institution	Materials covered
1	U. of Alaska, Reed College	Introductory quantum mechanics and relativity
2	Bolt, Beranek & Newman	Introductory physics, problems testing use of mathematical models
3	U. of California, Irvine	Classical mechanics
4	CCP and U. of California, Irvine	Mechanics
5	Dartmouth College	Square-well problem. Optics lab calculations. Vibrational spectrum, density of states of a square lattice.
6	Dartmouth College	Orbits under various force laws. Field and potential plotting. Charged particles in e-m fields.
7	Florida State U.	General physics
8	Florida State U.	General physics
9	Harvard U.	Mechanics Retarded time
10	Harvard U.	Principle of least action
11	U. of Illinois (CERL)	Auger electron experiment, other projects under development
12	MIT	Quantum mechanics Electrodynamics
13	MIT	A topic in special relativity
14	MIT	Dynamic systems (introductory)
15	U. of Michigan	Topics in general physics
16	U. of Minnesota	SHM; integration of F=MA for one dimension
17	Pennsylvania State U.	General physics
18	Reed College	Classical mechanics
19	U. of Rochester	Mathematical tools for elementary physics
20	Science Research Associates	Introductory physics and chemistry
21	Seattle Conference¶	Geometric optics lab unit; topics in introductory and intermediate physics
22	SUNY, Stony Brook	General physics
23	SUNY, Binghamton	General physics
24	Thomas J. Watson Research Center	Electricity and magnetism
25	US Naval Academy	50 programs treating problems in mechanics, electricity and magnetism
26	US Naval Academy; NY Inst. of Tech.	General physics
27	Wake Forest U.; MIT	General physics

Scope	Mode†	Status of testing	Computer	Language	Terminal type	Contact‡	References
Problems, Lab sessions	Comp	2 classes	IBM-1620 IBM-1130	FORTRAN	Console	Bork	21, 22
Problems	Comp, conv, sim, others	Preliminary research	PDP-1 PDP-7 SDS-940	TELCOMP, STRINGCOMP, LOGO & others	TTY-33 CRT	Feurzeig	2
Problems covering one quarter	Comp	Beginning with 160 students	IBM-360/50	ISIS, PL/I, CAL	IBM-2741 + card reader	Bork	23
One week	Comp	To be tested in January 1969	IBM-360/50 GE-635 SDS-940	FORTRAN, JOSS BASIC, PL/I	IBM-2741 TTY-33	Blum	15
Short sections	Comp	2 years	GE-235 GE-635 Datamet-30	BASIC	TTY-33, -35, -37; Friden	Luehrmann	14
Problems Lab projects	Comp, sim	1 year	GE-635	BASIC	TTY-33, -35, -37; Friden	Luehrmann	
One quarter course	Conv	Complete course given twice, for credit	IBM-1500	COURSEWRITER II	CRT (IBM-1510)	G. Schwarz	16, 24
Short tutorial sections for one quarter course	Conv	2 years	IBM-1440	COURSEWRITER I	Typewriter (IBM-1050)	Hansen	25
D Particular topics	Mixed	Not yet class tested	IBM-360/50	TOC	Special (The BRAIN)	Bork	
1 or 2 hours	Conv Graphic	Selected students, may be class tested soon (Irvine)	PDP-1	ASSEMBLY DECAL	DEC-340 (CRT) and Rand tablet with pen	Bork	3
One experiment	Mixed	Under test	CDC-1604	Modified FORTRAN; special teaching lang.	Special (CRT and TTY)	Risser	26
Film loops	Computer-made films		PDP-7	FORTRAN	DEC-340	J. Schwartz	7, 8, 27, 28, 29, 30
One week	Conv	Used with a few students	IBM-7094	ELIZA	Typewriter (IBM-2741)	Taylor	5
Short introductory sections based on problems	Sim		IBM-7094 (CTSS)	Special	TTY	Rosenberg	31
Short sections	Conv	Tested with a few students	IBM-7010	COURSEWRITER	Typewriter (IBM-1050)	Zinn	
Short lab sections	Comp	Being used by large classes	GE-265; CDC-3300	BASIC FORTRAN	TTY	Roll	
Course segments	Conv	Preliminary investigations	IBM-1410	COURSEWRITER I	Typewriter (IBM-1050)	Hall	
Problems Lab sessions	Comp	60 students per year, 4 years	IBM-1620 IBM-1130	FORTRAN JOSS	Console	Bork	17, 32, 33, 34, 35, 36, 37
Short sections	Conv	None	IBM-1401	COURSEWRITER	Typewriter (IBM-1050)	Plyter	
Short sections	Sim, user programs	Cursory	IBM-1500 IBM-360, other	APL	Typewriter	Mill	
Short sections	Conv	Optics tested at SUNY, Stony Brook	IBM-1440 IBM-7010	COURSEWRITER I	Typewriter (IBM-1050)	Commission on College Physics	1
Pace exams	Conv		IBM-1500	COURSEWRITER	CRT (IBM-1510)	Skolnick	
Short sections	Conv, comp	Full course being given	IBM-360/40	APL	Typewriter (IBM-1050)	Stannard	
Laboratory simulations	Sim	Under evaluation at two universities	IBM-1500	COURSEWRITER II	CRT (IBM-1510)	Lindsay	
Programmed problems worked by students outside class	Conv, comp	Course given once; testing and evaluation continue	GE-420	BASIC	TTY-33	Vierling or Jones	38, 39
One semester of two-semester course in general physics	Conv, comp, sim	In progress	IBM-1500	COURSEWRITER II	CRT (IBM-1510)	Nixon or Vierling	
Problems; review scripts	Conv	Tested with two groups of students	IBM-7094	ELIZA	TTY-35	Brehme	40



MULTILOOP DC NETWORK displayed on cathode-ray tube of IBM-1500 system. Student is required to make appropriate response with light pen during experiment. Computer gives him data as he puts voltmeter and ammeter into circuit. —FIG. 8

cuit. He does this by touching each terminal and the node to which he wants to connect it with the light pen. Values of voltage and current will appear on the meter face.

The student can open and close any switch by touching it with the light pen, thus causing its position to change. Other options for the student are to touch DATA when he wishes to obtain a reading or experimental numbers, SHOW to see a record of some of his previous measurements and ANSWER when he is ready to enter his results. Touching HELP brings him information necessary for the experiment, including a statement of the problem, instructions for making settings, description of theory, useful constants, etc.

OUTLOOK

It is clear from our table that the majority of computer-assisted-instruction projects in physics are still in the early testing stage. Detailed descriptions available are more often proposals rather than reports, and evaluations are more speculative than conclusive. Thus it is difficult to draw many general conclusions about the usefulness of these techniques although it is quite possible to develop a real enthusiasm for them and an optimistic outlook for their future.

Bork, now at the University of California, Irvine, was one of the first to suggest that computers will play an important part in physics teaching. "Advantages for both the science and nonscience major include the excitement generated by the computer itself, the possibility of seeing many cases worked out and the detailed contributions the computer can make in overcoming some of the students' mathematical limitations."¹⁷ Bork expects that the real power of the computer will come into play with the use of visual terminals, making possible instructional modes that can not be handled in any other way.

Difficulties, effectiveness

Because much intermediate physics consists of the application of differential equations to physical problems, it is not surprising that many instructional projects use the computer for their solution. Rather than spend time on mathematical methods of solution, the student can use the computer program for them and concentrate on physical interpretation. This great advantage must be evaluated in the light of possible drawbacks to the student, who often finds the mathematical methods somewhat mysterious. Introduction of the computer into this process may remove the student one more step from direct involvement, heightening the

element of mystery. On the other hand, when a student writes his own program, he must analyze the physical principles involved, thus enhancing his understanding of them.

Some disappointment was expressed by Taylor⁵ in discussing the reactions of MIT students to ELIZA in his special-relativity project. Although the students interviewed were enthusiastic about computer tutoring, Taylor felt that "student reluctance to direct his own education while trying to exploit the computer as a tutor . . . is more serious than any of the technical difficulties of the present system." He suggests that in the highly competitive and grade-conscious environment of some schools a student will tend to avoid the responsibility of making his own choices for fear of lowering the level of his academic performance.

There are other instructional goals for which the computer seems particularly well suited, however. It has been pointed out by Joseph H. Kanner¹⁸ that, although the knowledge of human learning is still fragmentary, we know that "repeating something increases the probability of the learner remembering the information" and "telling the learner immediately that he is right or wrong also facilitates learning." The unlimited patience of the computer can be exploited in going over material as often as a student desires and with any number of students on an individual basis. In addition it will tell the student immediately whether he is right or wrong with explanations if desired. Many students who hesitate to ask questions in class fearing disapproval or ridicule will feel at ease working with an impersonal, mechanized "tutor." The computer as a tutor proved both popular and successful in the review lessons written at Florida State University for use with a course in general-education physics. The lessons were a preliminary to development of the complete computer-guided course.¹⁶

What does it cost?

Cost must be considered. Karl Zinn has stated in an excellent review article,¹⁹ "I do not intend to sell a potential user on instructional applications of computers; the cost can be high and the benefits are still in question. I do hope to influence other readers to invest research dollars and personnel resources in work needed to make the systems and teaching strategies usable." The question of cost that

he raises is difficult to answer, but in a recent editorial in *Science* Philip H. Abelson²⁰ reports, "Under development at the University of Illinois is a facility aimed at exploiting the great time-sharing potential of the CDC-6600 computer. If development work is successful, the facility will eventually include about 4000 consoles . . . The hoped-for cost per student per hour of use is 25 cents." Cost considerations should also include the considerable demand on time and effort of physicists who design the instructional materials.

Computer-assisted instruction in physics is still in its early stages, but rapidly growing. It would be wise to keep in mind Kanner's plea to its proponents for "a moratorium on promises not yet supported by facts, the establishment of criteria describing limitations as well as the reasonable implications of research efforts, and the recognition that computer-assisted instruction is in competition in the market place with long established alternative methods of teaching."¹⁸ But some supporting facts are emerging, and the varied and imaginative uses of the computer are encouraging. It appears likely that the degree to which its potential is realized will depend not so much on the capabilities or cost of the systems as on the persistence and quality of the efforts put into their exploration. We conclude that the introduction of the computer into physics instruction represents a significant development in a field that is in great need of new ideas.

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We are indebted to the many who responded promptly in detail to our survey and for helpful cooperation from those active in computer-assisted instruction. We have had partial support from the US Navy under Project Themis Grant No. N 00014-68-0494, from The Alfred P. Sloan Foundation under Grant-in-Aid No. 68-7-4, and from the National Science Foundation.

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