J. EDUCATIONAL TECHNOLOGY SYSTEMS, Vol. 1(1), pp. 5-27, June, 1972

Digital Simulation In Education

PROFESSOR LUDWIG BRAUN
Director, Huntington Project
Polytechnic Institute of Brooklyn

ABSTRACT

A set of circumstances is described in which direct experimental experience is not available to the student, and in which simulation by digital computer is proposed as an alternative. Sample runs of three simulation programs are presented. The documentation and evaluation efforts of the *Huntington Two* Project are described and the costs of providing computer capability are presented.

Introduction

Since the introduction of the ENIAC computer in 1946, educators have found many ways of using computers in their academic programs. At the high-school level, computers are used primarily for administrative purposes; while at the college level, the computer is used for educational purposes as well as for administrative ones. These educational uses at the college level have been associated primarily with programming courses, or with large-scale or difficult computations (e.g., in nonlinear, or distributed systems).

One mode of computation which has been largely ignored among educators is the simulation mode. One notable exception is Huggins' JOBSHOP.[1] Medical schools are beginning also to explore the uses of simulations in development of diagnostic technique,[2] as well as in other ways.

Huggins[3] has characterized the digital computer as a highly-flexible laboratory in which we may explore any environment we wish. It is with this mode of computer utilization that we shall be concerned in this paper.

doi: 10.2190/JT2J-QBG1-55J7-59CG
http://baywood.com

The author has been working for seven years with high-school teachers in explorations of the utility of computer simulations in their curricula. Simulation programs have been found to be effective in biology, chemistry, earth science, physics, and the social sciences.[4]

In the following paragraphs, we shall explore the circumstances under which simulations are useful, and shall present several examples of simulation programs which have been developed recently.

What is Simulation?

Before we proceed, we should define what we mean by the term "simulation." The term is widely used, but seldom well defined. A carefully-developed definition and philosophical discussion of simulation is given by C. West Churchman.[5] A somewhat less precise definition of the verb "to simulate" which will suffice for our purposes is:

> *to simulate*: to represent a system by a model, and, generally, to perform experiments on that model.

This definition is very broad, and covers such diverse situations as the Link trainer (used to train pilots), the game of Monopoly (which simulates certain aspects of the world of finance), and the many computer simulations used in the Apollo missions to train astronauts, and to evaluate alternatives when a crisis occurs (as was done during the abortive Apollo 13 mission).

Actually, we haven't improved the level of our understanding very much. In the definition above, we have used the term "model"—a term which usually is understood to mean an attractive young lady, or a small-scale replica of a physical entity (e.g., a model airplane). We use it here to mean a simplified representation of a real-world system. In this sense a road map is a model of a particular geographic region; however, we shall concern ourselves here only with mathematical models—i.e., models which represent a physical system by a set of mathematical equations.

Each of the simulations presented below is modeled by a set of equations whose solution is implemented on a digital computer. In some cases, the implementation could have been realized in other ways (e.g., using a general-purpose, or a special-purpose, analog computer); but digital-computer realization was chosen because of the broad range of problems which it can handle.

A Rationale for Simulation

Few people would dispute the desirability of learning by direct experience. The investment of billions of dollars by our universities, and by our primary and secondary schools in laboratory facilities is evidence enough. Generation after generation of students re-measure the acceleration due to gravity, or re-discover Ohm's Law, or study the giant chromosomes of the drosophila fly, even though these things have been done by very capable scientists employing the most elaborate facilities available. How much easier (and how much less expensive) it would be to describe Millikan's oil-drop experiment, and its results, along with pictures of the apparatus, in a textbook—yet many physics laboratories in high schools and colleges are equipped with this apparatus, and, every year, legions of students repeat this experiment. Their e/m ratios are very imprecise compared to the carefully-determined value of the physicist; however, they have benefitted from having had the experience themselves. This is as true for non-scientists, who never again will have a laboratory experience, as it is for the physicist who will spend his life in the laboratory.

Even though direct experience is very desirable, our students frequently are prevented from such learning experiences. Some of the reasons for this are:

1. The necessary equipment is not available because of expense or it is too complex or delicate to permit students to use it (e.g., in high-energy physics).
2. The sample size available in the real world is too small to permit generalizations. (This is especially true in the training of medical students in the diagnosis of disease. Medical students in New York State, for example, run into very few cases of malaria, and develop little experience with it.)
3. The experimental technique is difficult and must be developed over an extended period (e.g., in experiments in genetics, and in titration).
4. There are serious dangers to the student (e.g., where radiation or high temperatures are involved, where there may be explosive mixtures of gases, or where highly-toxic materials are required).
5. The time scale is too short or too long to permit the student to make observations (e.g., the runaway of a nuclear

reactor—here, of course, there are other reasons for not permitting students to do the experiment—or the study of the dynamics of population).

6. The opportunity to experiment directly is not available (e.g., in studies of economic, political, or social systems, or in studies of human genetics, or spread of disease).
7. When measurement and other noise obscures the important phenomena (in the computer, we can create a world in which there is no noise and in which instruments are perfect, and *then* show the student how these things obscure the data of interest).

If any of the foregoing circumstances exists, the student normally is excluded from learning by direct experience. Typically, here, he learns by reading a textbook, or by attending a lecture on the subject. In both cases, the learning is less than completely satisfactory. (Who would accept a surgeon who has learned surgery solely from books and lectures?)

Simulation is an educational tool which can overcome the foregoing inhibitions; and which can provide, in many cases, a far better learning situation than can be provided by either textbooks or lectures.

It should be emphasized that simulation is proposed as a complement to existing educational techniques, rather than as a substitute for any of them.

Some Examples of Educational Simulations

The author and his colleagues in Huntington Two have over thirty simulation packages under development or completed. These simulations were developed originally for high-school students in courses in biology, chemistry, physics, and social studies; however, they have been found to be appropriate also for college students, at least at the freshman level. (They have been used at over twenty-five colleges.)

Several examples of these simulations are described below to exemplify the work of the Huntington Two group.

MARKET

This program simulates a two-company, single-product competitive market situation. Two students, or two groups of students, each representing one of the companies, make decisions about the production level, the advertising budget, and the unit price of the product for their company during the forthcoming quarter. After these decisions are entered into the computer, it prints out a marketing summary, which indicates the results of these decisions. For each company, the report lists:

a. profit
b. percentage share of the market
c. cash on hand
d. number of units sold
e. number of units in stock (inventory)
f. total assets.

Players make their decisions for the following quarter on the basis of these reports.

If the demand for one company's product turns out to be larger than the total of the production level and inventory (as of the start of a quarter) the company will sell out its stock without realizing its full sales potential. Any additional sales that could have been made will not be given to the other company by the computer.

The companies are penalized for overproduction. An inventory charge at the rate of 5% per quarter will be made for stock on hand at the end of a quarter. That is, 5% of the total value of the inventory (based on variable production cost) will be deducted from the company's cash on hand.

It is possible for a company to have a negative value for cash on hand. This means that the company must go into debt for this amount, and an additional 5% charge will be made on the debt.

The game ends when one company goes bankrupt or accumulates 12 million dollars in total assets.

Part of the sample run of this program is shown below, to indicate the nature of the responses. Several specific aspects of this sample run should be noted:

1. Until quarter 3, neither company does any advertising. At this point, company 1 decides to mount a significant advertising campaign, and, as a result, acquires two thirds of the sales for this quarter, even though its unit price is higher than that of company 2.

2. In quarter 4, both companies advertise, and the positive effect of a higher advertising budget for company 1 is offset almost completely by its higher price. In addition, in this quarter, the total number of units sold goes from 10,000 (all units and dollars in the print-out are in thousands) to 81,000, because company 2 has added significantly to the total spent for advertising,
3. In quarter 5, we see the occurrence of two of the random events which are built into the program (wage-price freeze and fire damage.)

Sample Run of Market

```
DO YOU WANT INSTRUCTIONS(TYPE 1 FOR YES, 0 FOR NO)? 1

MARKET SIMULATES THE COMPETITION BETWEEN TWO COMPANIES
SELLING A PRODUCT DIFFERENTIATED BY BRAND ADVERTISING.
THE QUANTITY EACH COMPANY SELLS IS DEPENDENT UPON PRICE
AND ADVERTISING BUDGET. THE GAME ENDS WHEN ONE
COMPANY GOES BANKRUPT OR REACHES  12  MILLION IN
TOTAL ASSETS.

ARE YOU BEGINNING THE GAME OR CONTINUING
(TYPE 1 FOR BEGINNING, 2 FOR CONTINUING)? 1


FIXED PRODUCTION COST=$ 250000 / QUARTER
VARIABLE PRODUCTION COST=$ 20 /UNIT
WITH NO ADVERTISING AND A SELLING PRICE OF $50/UNIT
A COMPANY WILL SELL  25000  UNITS (PRINTED AS  25 )
WAREHOUSE  CHARGE FOR INVENTORY= 5  PER CENT
INTEREST CHARGE ON BORROWED MONEY= 5  PER CENT



UNITS AND DOLLARS BELOW ARE IN THOUSANDS


QUARTER  0

PROFIT  MARKET SHARE  CASH ON HAND  NUMBER SOLD  INVENTORY  ASSETS
 0        0              5000           0           100        7000
 0        0              5000           0           100        7000



COMPANY  1
PRODUCTION LEVEL? 25
ADVERTISING BUDGET? 0
UNIT PRICE? 50


COMPANY  2
PRODUCTION LEVEL? 25
ADVERTISING BUDGET? 0
UNIT PRICE? 50
```

```
QUARTER  1

PROFIT  MARKET SHARE  CASH ON HAND  NUMBER SOLD  INVENTORY  ASSETS
 400     50            5400          25           100        7400
 400     50            5400          25           100        7400



COMPANY  1
PRODUCTION LEVEL? 0
ADVERTISING BUDGET? 0
UNIT PRICE? 50

COMPANY  2
PRODUCTION LEVEL? 0
ADVERTISING BUDGET? 0
UNIT PRICE? 50

QUARTER  2

PROFIT  MARKET SHARE  CASH ON HAND  NUMBER SOLD  INVENTORY  ASSETS
 425     50            6325          25           75         7825
 425     50            6325          25           75         7825



COMPANY  1
PRODUCTION LEVEL? 10
ADVERTISING BUDGET? 500
UNIT PRICE? 55

COMPANY  2
PRODUCTION LEVEL? 10
ADVERTISING BUDGET? 0
UNIT PRICE? 50

QUARTER  3

PROFIT  MARKET SHARE  CASH ON HAND  NUMBER SOLD  INVENTORY  ASSETS
 785     64.28         7810          45           40         8610
 440     35.71         7065          25           60         8265



COMPANY  1
PRODUCTION LEVEL? 45
ADVERTISING BUDGET? 500
UNIT PRICE? 55

COMPANY  2
PRODUCTION LEVEL? 25
ADVERTISING BUDGET? 300
UNIT PRICE? 50
```

```
QUARTER  4

PROFIT  MARKET SHARE  CASH ON HAND  NUMBER SOLD  INVENTORY  ASSETS
 641       50.61          8371          41           44        9251
 605       49.38          7970          40           45        8870

NEW LABOR CONTRACT - VARIABLE PRODUCTION COST NOW= $ 21 /UNIT


COMPANY  1
PRODUCTION LEVEL? 40
ADVERTISING BUDGET? 400
UNIT PRICE? 53


COMPANY  2
PRODUCTION LEVEL? 40
ADVERTISING BUDGET? 350
UNIT PRICE? 50


QUARTER  5

PROFIT  MARKET SHARE  CASH ON HAND  NUMBER SOLD  INVENTORY  ASSETS
 660       48.8           9008          41           43        9911
 647       51.19          8635          43           42        9517

THE PRESIDENT HAS JUST IMPOSED A WAGE-PRICE FREEZE ON THE
ECONOMY, AND YOU MAY NOT RAISE THE PRICE OF YOUR PRODUCT
OVER THE NEXT 2 QUARTERS.

COMPANY 1  HAS SUFFERED FIRE DAMAGE IN ITS WAREHOUSE
ALL UNITS WERE DESTROYED. YOUR INSURANCE WILL REIMBURSE YOU
IN THE AMOUNT OF $ 677  FOR THESE UNITS



COMPANY  1
PRODUCTION LEVEL? 70
ADVERTISING BUDGET? 250
UNIT PRICE? 53


COMPANY  2
PRODUCTION LEVEL? 50
ADVERTISING BUDGET? 325
UNIT PRICE? 50
```

POLUT

The POLUT program simulates the effect on dissolved oxygen and waste level in a body of water of the dumping of wastes into the body of water. The student has the capability of varying any combination of five parameters. These parameters are:

a. Kind of body of water (pond, lake, slow-moving stream, or fast-moving stream)
b. Temperature of the water (to simulate seasonal variations, or to permit an exploration of some of the effects of thermal pollution)
c. Kind of waste (human or industrial)
d. Rate of dumping of waste
e. Type of treatment (none, primary, or secondary).

The program generates plots of oxygen and waste levels as functions of time, assuming that the water initially is as pure as that in a pristine mountain stream.

Several sample runs of POLUT are shown below to indicate the character of the program output.

Water Pollution Study (Sample Runs)

```
INSTRUCTIONS (1=YES, 0=NO)? 1

IN THIS STUDY YOU CAN SPECIFY THE FOLLOWING CHARACTERISTICS:

A. THE KIND OF BODY OF WATER:
   1. LARGE POND
   2. LARGE LAKE
   3. SLOW-MOVING RIVER
   4. FAST-MOVING RIVER

B. THE WATER TEMPERATURE IN DEGREES FAHRENHEIT:

C. THE KIND OF WASTE DUMPED INTO THE WATER:
   1. INDUSTRIAL
   2. SEWAGE

D. THE RATE OF DUMPING OF WASTE, IN PARTS PER MILLION (PPM)/DAY.

E. THE TYPE OF TREATMENT OF THE WASTE:
   0. NONE
   1. PRIMARY (SEDIMENTATION OR PASSAGE THROUGH FINE
               SCREENS TO REMOVE GROSS SOLIDS)
   2. SECONDARY (SAND FILTERS OR THE ACTIVATED SLUDGE
                 METHOD TO REMOVE DISSOLVED AND COLLOIDAL
                 ORGANIC MATTER)
```

Several comments are in order with respect to the foregoing runs:

a. Comparison of Run 1 with Run 2 shows the effect of going from a slow-moving stream to a fast-moving stream.
b. Comparison of Runs 1 and 3 reveals the improvement achievable with primary treatment of sewage prior to dumping.
c. Comparison of Runs 3 and 4 reveals the effect of a significant increase in dumping rate.

```
***********

BODY OF WATER? 3
WATER TEMPERATURE? 60
KIND OF WASTE? 1
DUMPING RATE? 10
TYPE OF TREATMENT? 0


DO YOU WANT: A GRAPH(1), A TABLE(2), OR BOTH(3)? 1



AFTER DAY 3  THE FISH BEGIN TO DIE, BECAUSE
THE OXYGEN CONTENT OF THE WATER DROPPED BELOW 5 PPM.


       0...OXYGEN-SCALE....5...OXYGEN-SCALE...10...OXYGEN-SCALE...15
       0..WASTE.10..SCALE.20..WASTE.30..SCALE.40..WASTE.50..SCALE.60
DAY    I---------I---------I---------I---------I---------I---------I
 0    I   W                              O
 1    I            W                  O
 2    I                   W       O
 3    I                      0 W
 4    I                   0        W
 5    I                 0             W
 6    I               0                  W
 7    I             0                      W
 8    I            0                        W
 9    I           0                           W
 10   I          0                            W
 11   I          0                             W
 12   I         0                               W
 13   I         0                               W
 14   I        0                                 W
 15   I        0                                 W
 16   I        0                                 W
 17   I        0                                 W
 18   I        0                                 W

THE WASTE CONTENT AND OXYGEN CONTENT WILL REMAIN AT
THESE LEVELS UNTIL ONE OF THE VARIABLES CHANGES.
```

RUN 1

d. Comparison of Runs 1 and 5 reveals the effect of going from summer conditions (water temperature = 60°) to winter conditions (water temperature = 35°).

This program is useful in courses in social studies, as well as in courses in biology, ecology, or earth science, and is appropriate also for a team-teaching situation involving biology and social-studies teachers. It can also be used with a new course called "The Man-Made World."[6]

```
***********

BODY OF WATER? 4
WATER TEMPERATURE? 60
KIND OF WASTE? 1
DUMPING RATE? 10
TYPE OF TREATMENT? 0


DO YOU WANT: A GRAPH(1), A TABLE(2), OR BOTH(3)? 1



       0...OXYGEN-SCALE....5...OXYGEN-SCALE...10...OXYGEN-SCALE...15
       0..WASTE.10..SCALE.20..WASTE.30..SCALE.40..WASTE.50..SCALE.60
DAY    I---------I---------I---------I---------I---------I---------I
 0    I   W                                 O
 1    I            W                      O
 2    I                   W            O
 3    I                        W     O
 4    I                            WO
 5    I                            0  W
 6    I                           0       W
 7    I                          0         W
 8    I                         0           W
 9    I                         0             W
 10   I                         0             W
 11   I                        0               W
 12   I                        0                W
 13   I                        0                W
 14   I                        0                 W
 15   I                        0                 W
 16   I                        0                 W
 17   I                        0                 W
 18   I                        0                 W

THE WASTE CONTENT AND OXYGEN CONTENT WILL REMAIN AT
THESE LEVELS UNTIL ONE OF THE VARIABLES CHANGES.
```

RUN 2

```
***********

BODY OF WATER? 3
WATER TEMPERATURE? 60
KIND OF WASTE? 1
DUMPING RATE? 10
TYPE OF TREATMENT? 1


DO YOU WANT: A GRAPH(1), A TABLE(2), OR BOTH(3)? 1



       0...OXYGEN-SCALE....5...OXYGEN-SCALE...10...OXYGEN-SCALE...15
       0..WASTE.10..SCALE.20..WASTE.30..SCALE.40..WASTE.50..SCALE.60
DAY    I---------I---------I---------I---------I---------I---------I
 0     I   W                              O
 1     I       W                         O
 2     I           W                  O
 3     I             W              O
 4     I               W           O
 5     I                 W       O
 6     I                  W     O
 7     I                    W   O
 8     I                     W O
 9     I                      W O
 10    I                      WO
 11    I                      WO
 12    I                       W
 13    I                      0W
 14    I                      0W
 15    I                      0W
 16    I                      0W
 17    I                      0W

THE WASTE CONTENT AND OXYGEN CONTENT WILL REMAIN AT
THESE LEVELS UNTIL ONE OF THE VARIABLES CHANGES.
```

RUN 3

```
***********

BODY OF WATER? 3
WATER TEMPERATURE? 60
KIND OF WASTE? 1
DUMPING RATE? 14
TYPE OF TREATMENT? 1


DO YOU WANT: A GRAPH(1), A TABLE(2), OR BOTH(3)? 1



AFTER DAY 6  THE FISH BEGIN TO DIE, BECAUSE
THE OXYGEN CONTENT OF THE WATER DROPPED BELOW 5 PPM.


       0...OXYGEN-SCALE....5...OXYGEN-SCALE...10...OXYGEN-SCALE...15
       0..WASTE.10..SCALE.20..WASTE.30..SCALE.40..WASTE.50..SCALE.60
DAY    I---------I---------I---------I---------I---------I---------I
 0    I   W                              O
 1    I         W                      O
 2    I              W              O
 3    I                  W       O
 4    I                    W   O
 5    I                      0W
 6    I                    0    W
 7    I                   0      W
 8    I                   0       W
 9    I                  0         W
 10   I                 0          W
 11   I                 0           W
 12   I                 0           W
 13   I                0             W
 14   I                0             W
 15   I                0             W
 16   I                0             W
 17   I                0             W

THE WASTE CONTENT AND OXYGEN CONTENT WILL REMAIN AT
THESE LEVELS UNTIL ONE OF THE VARIABLES CHANGES.


ANOTHER RUN (1=YES, 0=NO)? 1


***********
```

RUN 4

```
***********

BODY OF WATER? 3
WATER TEMPERATURE? 35
KIND OF WASTE? 1
DUMPING RATE? 10
TYPE OF TREATMENT? 0

DO YOU WANT: A GRAPH(1), A TABLE(2), OR BOTH(3)? 1


       0...OXYGEN-SCALE....5...OXYGEN-SCALE...10...OXYGEN-SCALE...15
       0..WASTE.10..SCALE.20..WASTE.30..SCALE.40..WASTE.50..SCALE.60
DAY    I---------I---------I---------I---------I---------I---------I
 0    I  W                                                 O
 1    I          W                                      O
 2    I                 W                          O
 3    I                      W                 O
 4    I                          W          O
 5    I                             W  O
 6    I                              0 W
 7    I                             0    W
 8    I                            0      W
 9    I                           0         W
 10   I                          0          W
 11   I                         0            W
 12   I                         0             W
 13   I                         0             W
 14   I                        0               W
 15   I                        0               W
 16   I                        0               W
 17   I                        0               W
 18   I                        0               W

THE WASTE CONTENT AND OXYGEN CONTENT WILL REMAIN AT
THESE LEVELS UNTIL ONE OF THE VARIABLES CHANGES.
```

RUN 5

SCATRA

SCATRA is a physics program which simulates the scattering of alpha particles by atoms of heavy metals in a thin foil. In this simulation, the student has the opportunity to explore the validity of three different models of atomic structure—the hard-sphere model; the Thomson, or plum-pudding model; or the Rutherford, or planetary model. By comparing the scattering patterns of these three models with those which result from a real-world scattering experiment, the student can evaluate the relative validity of these models.

For each model, the student is able to specify the energy of the incident particles, the material of the target foil, and the initial x-axis positions of the target particles. After the student specifies the model to be used, and the foregoing parameters, the computer prints the trajectories of three particles at the specified locations, as well as the boundary of the target atom.

Four runs of this program are shown below. In the first three runs, the parameters (particle energy, target material, and initial x-position) are fixed and only the model of atomic structure is changed. In the fourth, an additional run of the Thomson model is made for different starting positions for the incident particles. In this latter run, two of the particles encounter "plums" in the "pudding."

This simulation has two valuable aspects: first, it provides the student with an opportunity to conduct experiments which he is not likely to be able to conduct in the real world; and second, it gives the student an opportunity to learn something about the concept of modeling, by permitting him to compare three models which have been proposed for atomic structure.

```
WHICH MODEL? 1
E= .1     ? .1
Q= 79     ? 79
X( 1   ) =-80    ? -80
X( 2   ) =-40    ? -40
X( 3   ) = 10    ? 10

              HARD SPHERE MODEL

PARTICLE ENERGY = .1  MEV          TARGET CHARGE = 79  UNITS

       DISTANCE (PICOMETERS = 10↑(-12) METERS)
     -120        -80        -40        0         +40        +80       +120
       I---------I---------I---------I---------I---------I---------I
-140  I          1         2           3        3

-126  I          1         2           3       3

-112  I          1         2           3     3

-98   I          1         2           3    3

-84   I          1         2           3  3

-70   I          1         2           3 3

-56   I          1         2           3

-42   I          1         2  B              B

-28   I        2 1         B                    B

-14   I          1       B                        B

 0    I          1       B                         B

 14   I          1       B                        B

 28   I          1         B                    B

 42   I          1            B              B

 56   I          1

 70   I          1

 84   I          1

 98   I          1

 112  I          1

 126  I          1

 140  I          1

       I---------I---------I---------I---------I---------I---------I
PARTICLE 2  OFF SCALE AT:  X=-136   Y=-14
PARTICLE 3  OFF SCALE AT:  X= 52   Y=-154
```

```
     TRAJECTORY PLOTS OF SCATTERED ALPHA PARTICLES

1=HARD-SPHERE, 2=THOMSON, 3=RUTHERFORD, 4=END PROGRAM
WHICH MODEL? 3
INPUT PARTICLE ENERGY, IN MEV, .01<=E<=100, E= .1    ? .1
INPUT TARGET CHARGE, AN INTEGER, 1<=Q<=100, Q= 79    ? 79
INPUT INITIAL X-POSITION FOR THREE PARTICLES,
     IN PICOMETERS, -120<=X( )<=+120
X( 1  ) =-80    ? -80
X( 2  ) =-40    ? -40
X( 3  ) = 10    ? 10


              RUTHERFORD MODEL

PARTICLE ENERGY = .1  MEV          TARGET CHARGE = 79  UNITS

       DISTANCE (PICOMETERS = 10↑(-12) METERS)
     -120       -80       -40        0       +40       +80      +120
       I---------I---------I---------I---------I---------I---------I
-140  I          1         2           3
-126  I          1         2           3
-112  I          1         2           3
-98   I          1         2           3
-84   I          1         2           3
-70   I          1         2           3
-56   I          1         2           3
-42   I          1         2  B        3    B
-28   I          1         B           3       B
-14   I          1       B 2            3        B
 0    I          1       B 2         N  3         B
 14   I          1       B 2            3        B
 28   I          1         B             3     B
 42   I          1         2  B           3 B
 56   I          1         2               3
 70   I          1        2                3
 84   I          1        2                 3
 98   I          1        2                  3
 112  I          1        2                   3
 126  I          1        2                    3
 140  I          1        2                     3

       I---------I---------I---------I---------I---------I---------I
```

```
WHICH MODEL? 2
E= .1     ? .1
Q= 79     ? 79
X( 1   ) =-80    ? -80
X( 2   ) =-40    ? -40
X( 3   ) = 10    ? 10

              THOMSON MODEL

PARTICLE ENERGY = .1  MEV          TARGET CHARGE = 79  UNITS

       DISTANCE (PICOMETERS = 10↑(-12) METERS)
     -120       -80       -40        0        +40       +80      +120
       I---------I---------I---------I---------I---------I---------I
-140  I          1         2           3

-126  I          1         2           3

-112  I          1         2           3

-98   I          1         2           3

-84   I          1         2           3

-70   I          1         2           3

-56   I          1         2           3

-42   I          1         2  B        3    B

-28   I          1         B            3      B

-14   I          1       B 2            3        B

 0    I          1       B 2            3         B

 14   I          1       B 2            3        B

 28   I          1         B            3      B

 42   I          1         2  B         3   B

 56   I          1         2            3

 70   I          1         2            3

 84   I          1         2            3

 98   I          1        2             3

 112  I          1        2             3

 126  I          1        2             3

 140  I          1        2             3

       I---------I---------I---------I---------I---------I---------I
```

```
WHICH MODEL? 2
E= .1     ? .01
Q= 79     ? 79
X( 1  ) =-80    ? -35
X( 2  ) =-40    ? 0
X( 3  ) = 10    ? 20

                THOMSON MODEL
PARTICLE ENERGY = .01  MEV           TARGET CHARGE = 79  UNITS

      DISTANCE (PICOMETERS = 10↑(-12) METERS)
    -120       -80       -40        0        +40       +80      +120
      I---------I---------I---------I---------I---------I---------I
-140  I                    1        2    3

-126  I                    1        2    3

-112  I                    1        2    3

-98   I                    1        2    3

-84   I                    1        2    3

-70   I                    1        2    3

-56   I                    1        2    3

-42   I                    1 B      2    3 B

-28   I                   B1        2    3    B

-14   I                 B  1        2    3      B

0     I                 B  1        2     3      B

14    I                 B 1         2     3     B

28    I                   B         2      3  B

42    I                  1   B      2      B

56    I                 1           2       3

70    I                 1           2        3

84    I                1            2         3

98    I               1             2         3

112   I               1             2          3

126   I              1              2           3

140   I             1               2            3

      I---------I---------I---------I---------I---------I---------I
```

Huntington Two

In the period 1970-1972, the staff of Huntington Two (H2) has been developing simulations such as those described (see "Some Examples of Education Simulation"). These programs, along with substantial amounts of supporting material, have been provided to about 100 high schools, and 25 two-year colleges and universities all over the United States, in order to provide an evaluation of their educational effectiveness.

The supporting material consists of:

1. Background and enrichment material
2. Suggested preliminary preparation before using the program.
3. Questions for discussion after running the program.
4. Presentation of the mathematical model, its underlying assumptions, and discussion of the effect of violation of the assumptions.
5. Sample runs
6. Information on appropriate ranges for the model parameters.
7. Suggestions for classroom use of the program.
8. Program listing
9. Suggestions for modifications of the program logic, internal parameter values, or internal data values, to "customize" the program.
10. Student laboratory manual.

The material covers 60-80 pages, and contains more information than most teachers need—or want. To make the material useful to all teachers, it is arranged in layers of increasing complexity. The teacher who only goes through the first couple of layers has an adequate amount of information to use the program in his classes, without being burdened by information or sophistication beyond his needs; while the teacher who wants it has the more complete information available.

The effect of the Huntington Two simulation programs on the attitudes of students toward computers, and on their knowledge of the subjects related to the programs is being evaluated by a committee of educators headed by Dr. E. J. Piel, the Executive Director of the Engineering Concepts Curriculum Project. This evaluation effort includes also an attempt to identify improvements which might be made in the individual programs, and the ways in which the teachers and students have used them. (In POLUT, for example, several teachers have adjusted parameter values to correspond to conditions in a local river, in order to make the simulation more personal for their students.) The evaluation committee plans to complete its final report in the Fall of 1972.

There are a number of questions which arise naturally regarding the use of computer-related material. Some of these (along with possible answers) are:

1. What kind of equipment is required to utilize this kind of material and how much does it cost? The high schools and colleges which are using the H2 material have available a wide variety of computer facilities. These range from a small stand-alone computer with a single terminal at a cost of under $10,000 purchase price through terminals into small-scale time-sharing machines which can handle a dozen users simultaneously and which cost $60,000 to large-scale time-sharing machines which cost several million dollars and can service over 100 users at one time. In the large majority of cases, high-school users purchase computer time from commercial service bureaus at monthly costs ranging from $300-$500 for unlimited use; although this situation is likely to change in the next few years as stand-alone machines become easier to operate and less expensive to purchase. (This year's $10,000 computer is likely to cost only $3,000-$5,000 if present trends continue.)

2. How many high schools in the United States have access to computers of reasonable computing power for instructional purposes and what is a reasonable estimate of this number five years from now? It is difficult to obtain information on this point; however, it is reasonable to estimate that there already are over 3,000 high schools in this category, and that the fraction will increase to 50 per cent within five years. Over 90 per cent of the high schools in Rhode Island, and 50 per cent of those in Oregon and on Long Island have such capability now.

3. How can schools obtain programs such as those being developed by H2? Fortunately, the commercial publishers

have begun to perceive a market here. Some material already has been published, and the pace is quickening.

4. How many simulation packages does H2 expect to develop in the next two years, and in which disciplines? H2 is developing simulations in biology, physics, and social studies, and expects to complete sixty packages by the start of the 1974 school year.

5. Are there other areas and academic levels where simulation is valuable? The answer is a resounding yes! In medical education, for example, simulation could permit students to study physiological function in the normal and pathological states much more effectively than is done currently. A machine-shop teacher recently suggested that a computer simulation of a numerically-controlled machine tool would be useful to his students. They would be able to design tapes for this "numerically-controlled machine tool," and would be able to "operate" it. His students now get no experience with such machines, because they are too expensive, and because of the possibility for serious and costly damage from student error. Clearly, the areas of application of simulation are limited primarily by the imaginations of the teacher and of the developers of simulations.

Conclusion

The simulations described above have been received enthusiastically by high-school and college teachers all over the country. It has become very clear, during this development effort, that this enthusiasm exists, to a large degree, because of the extensive support material which has been supplied with each simulation. Whenever a simulation exists without this, only the developer and the exceptional teacher are able to use it. If simulations are to be exportable, the teacher must be provided with such support material. With such complete packages, computer simulation undoubtedly will play an important role in education at many levels, and in many disciplines, in the near future.

The author wishes to acknowledge the support which his efforts have received from the National Science Foundation through Grant GW-5883.

REFERENCES

1. K. J. Lutz, "The Homewood Electronic Jobshop," The Johns Hopkins University, Baltimore, Maryland, 1969.
2. J. E. Russo, "Exercise in Medical Diagnosis," Thesis for M.S. degree, Polytechnic Institute of Brooklyn, Brooklyn, New York, 1970.
3. W. H. Huggins, Private Communication.
4. Huntington Computer Project Teacher's Manual, Polytechnic Institute of Brooklyn, 1971.
5. C. W. Churchman, pp. 1-12, "Symposium on Simulation Models: Methodology and Applications to the Behavioral Sciences," A. C. Hoggat and F. E. Balderston (eds.), South-Western Publishing Co., Cincinnati, Ohio.
6. "The Man-Made World," developed by the Engineering Concepts Curriculum Project (ECCP), Webster Division, McGraw-Hill, Inc., 1971.