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ABSTRACT

A set of interactive, computer-simulated experiments was designed to respond to the large range of individual differences in aptitude and reasoning ability generally exhibited by students enrolled in first-semester general chemistry. These experiments give students direct experience in the type of decision making needed in an experimental setting. For instance, the student is encouraged to develop a strategy for empirical problem-solving, e.g., the determination of the first and second ionization potentials of an element. Generally, this strategy involves breaking the problem into three sequential phases: empirical, graphic, and symbolic. In the empirical phase, the student must select productive experimental conditions. While many students have difficulty in deciding which values produce meaningful results, first semester students in general chemistry can learn to make empirical decisions when given several computer-simulated experiments with a consistent pedagogic structure. (Author/LMM)

DECISION MAKING IN COMPUTER-SIMULATED EXPERIMENTS

by

J.P. Suits

and

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Slide #1:

DECISION MAKING IN COMPUTER-SIMULATED EXPERIMENTS

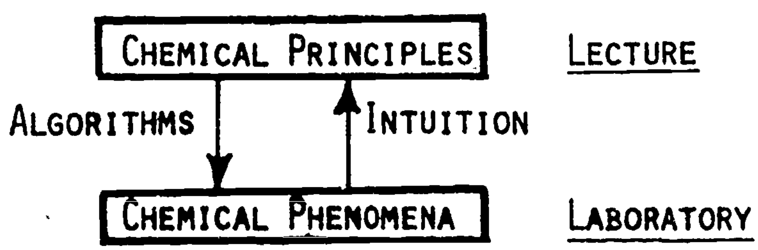
J.P. SUITS AND J.J. LAGOWSKI

Paper presented at the 183rd National Meeting of the American Chemical Society, Las Vegas, April 1982.

Computer-simulated experiments can provide a rich environment in which students manipulate experimental variables and see patterns in the resulting data. The types of decisions made in real laboratory work also apply to simulated experiments on the computer. Today, we will show how this decision-making process can be guided to a productive end.

Slide #2:

TRADITIONAL INSTRUCTION



Traditional instruction has all of the necessary levels in the structure of chemical knowledge. Lectures offer an efficient way to expalin chemical principles and to show how they relate one to another. On the other hand, laboratory work gives the student "hands on" experience with chemical phenomena. These two levels are tied together by homework problem sets which apply a chemical principle to data from a chemical phenomenon. However, difficulties often occur when students solve problem sets in a mechanical or algorithmic way without understanding. A second difficulty is the amount of time required for students to develop an intuition in regard to how chemical phenomena generate the data which is described by chemical principles.

Slide #3:

COMPUTER-SIMULATED EXPERIMENT

CHEMICAL PRINCIPLES	MEANING
EMPIRICAL DECISION MAKING	ORGANIZE
CHEMICAL PHENOMENA	ENCOUNTER

Computer-simulated experiemnts can be used to bridge the gap between phenomena and principles by organizing the middle ground between the two levels. The process by which chemical pheomena is organized relies upon a systematic approach which extracts order from a set of encounters with the complexities of nature. The decisions made in this process begin as trial-and-error attempts but are fine-tuned with the help of experience and guidance at appropriate times. In this talk we will show how the decisions made by a student can be made more effectively and efficiently.

Slide #4:

MODES OF DECISION MAKING

1. PREPARATORY MODE
2. EMPIRICAL MODE -- ENCOUNTER PHENOMENON
3. GRAPHIC MODE -- ORGANIZE PHENOMENON
4. SYMBOLIC MODE -- MEANING OF PHENOMENON

The type of decision making in a experimental setting is dependent upon the particular mode of the empirical investigation. In the preparatory mode the student is motivated and given background skills and facts for the experiment. In the empirical mode the student decides upon the experimental conditions and which facts must be recorded. In the graphic mode the data set is organized into a form in which a pattern may be seen. Finally, in the symbolic mode the student expresses the meaning of the pattern of data.

Slide #5:

TYPES OF GUIDANCE

1. CUES
2. FEEDBACK

How can we guide this decision-making process to a productive end? In general the types of guidance are cues and feedback. Cues are given in the form of a question or a statement made at the appropriate time. A cue is a device to focus attention on the important aspects of a situation. Feedback, on the other hand, occurs after a response has been made. It tells whether the response was correct or incorrect. Feedback can take many forms depending on the circumstances.

Cues are up-front occuring before a response is expected, whereas feedback is submerged and used only as necessary. The metaphor with an iceberg holds here, that is ...cues are seen and feedback is not. To promote efficient learning, include the fewest number of cues possible and as much feedback as the individual needs to avoid unproductive thinking or frustration.

Slide #6:

DECISIONS IN PREPARATORY MODE

1. WHY DO I NEED TO DO THIS EXPERIMENT?
2. WHAT WILL I DO TO ACCOMPLISH THIS?
3. WHEN WILL I KNOW I HAVE ACCOMPLISHED THIS?

The student must decide certain things before he does the experiment. He should understand <u>why</u> he needs to accomplish the objective, <u>what</u> procedure he will use, and <u>when</u> he will accomplish the objective. These global decisions are then replaced by more detailed ones during the simulated experiment. This is the process which Frederick Reif called "successive elaboration" in his talk on Monday in Dudley Herron's symposium on science education and chemistry teaching.

Slide #7:

POSE THE PROBLEM ...

"IN THIS SIMULATED EXPERIMENT YOU WILL USE A MELTING-POINT APPARATUS AND GRAPH OF TIME VS TEMPERATURE TO OBTAIN INFORMATION."

"HOW COULD YOU DETERMINE WHETHER YOUR SAMPLE IS A PURE SUBSTANCE OR A MIXTURE FROM THIS INFORMATION?"

For example, suppose the problem is to do a melting point experiment in order to distinguish between a pure substance and a mixture. Posing the problem shows the student the nature of the task he is to undertake and the complexity of the task. If he can not compose a verbal response, it tells him he does not know the general strategy to be used in solving the problem. The learner is then given a list of the major steps to be used in the solution of the problem.

Slide #8:

DECISIONS IN PREPARATORY MODE

5. WHAT DO I NEED TO KNOW BEFORE I JUMP INTO IT?

   (A) EMPIRICAL GENERALIZATIONS

   (B) EMPIRICAL FACTS

Appropriate background information is needed for the problem at hand. That is, certain facts and generalizations are essential in the performance during and after the experiment. This essential information must be internalized by the learner before he begins his detailed work on the problem task.

Slide #9:

EXAMPLE: RULES FOR COMPUTER LESSON # 1:

1. RELATIONSHIP OF PHYSICAL STATE AT ROOM TEMP. TO MELTING POINT;

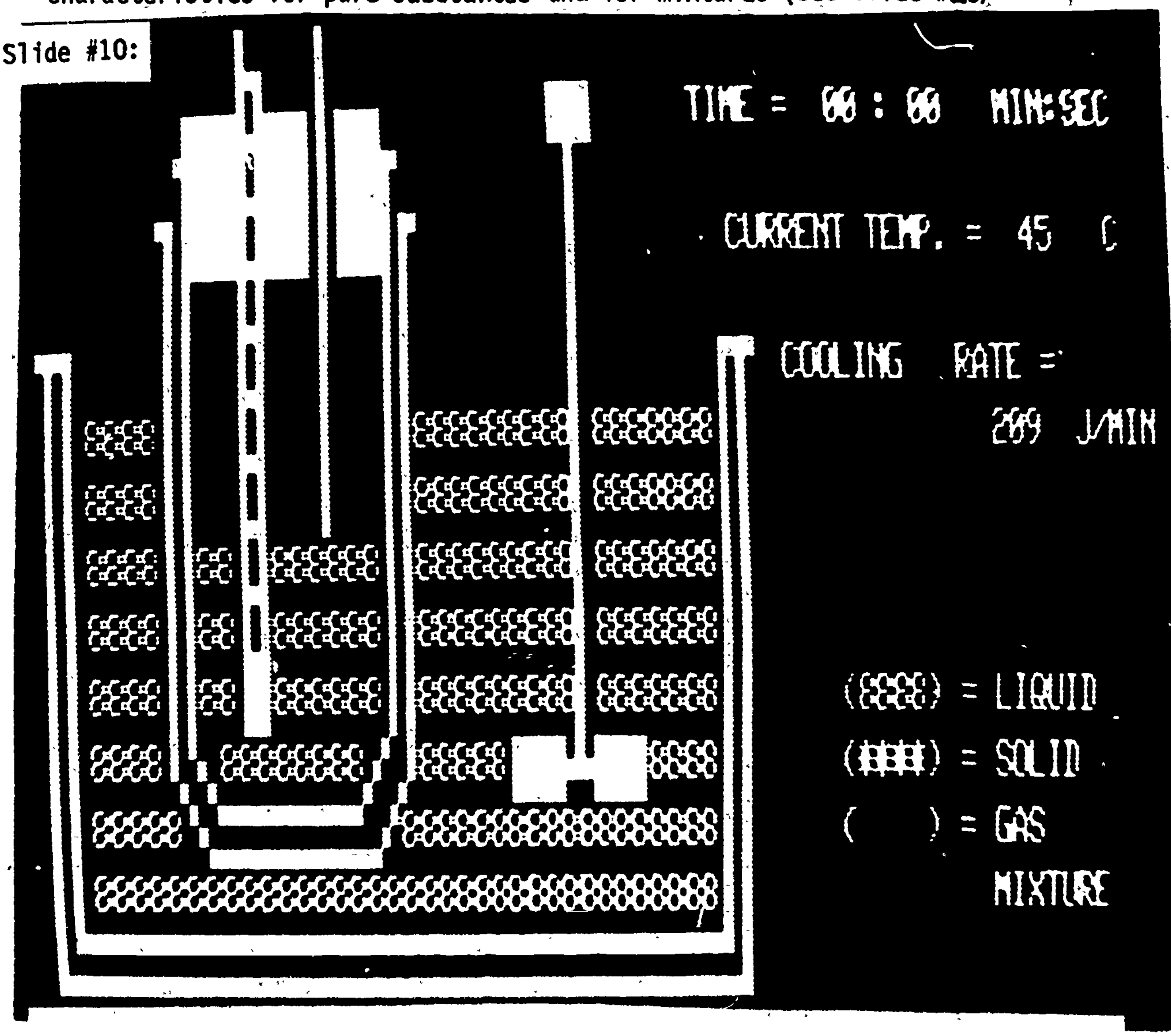
2. EMPIRICAL DEFINITION OF MELTING POINT;

3. MELTING OF A PURE SUBSTANCE;

4. MELTING OF A MIXTURE.

Here is an example of some of the generalizations needed in our melting point experiment. If the first or second generalization is not understood then the problem can not be solved. We are currently analyzing data to see if both the third and fourth generalizations can be intentionally deleted from the preparatory mode. The resulting instructional sequence is one in which the learner is guided to the nature of the melting characteristics through experimental work and comparisons with model characteristics for pure substances and for mixtures (see slide #20).

Slide #10:



Once you show this slide to a chemist and tell him the objective of this experiment...he only needs to know that this is a test tube (as shown by the arrow) and he can succeed at this task. Conversely, a first semester student needs to see each individual component drawn separately on the screen. Then he can cope with the complete display when he begins the experiment.

Slide #11:

DECISIONS IN EMPIRICAL MODE

1. WHERE DO I START?
2. WHICH DIRECTION DO I GO?
3. HOW FAST?

Next we turn to the empirical mode. The student has just been prepared, now he must establish initial conditions for the experiment. He must decide where to start, which way to go and the rate of change.

Slide #12:

A. EMPIRICAL MODE ...

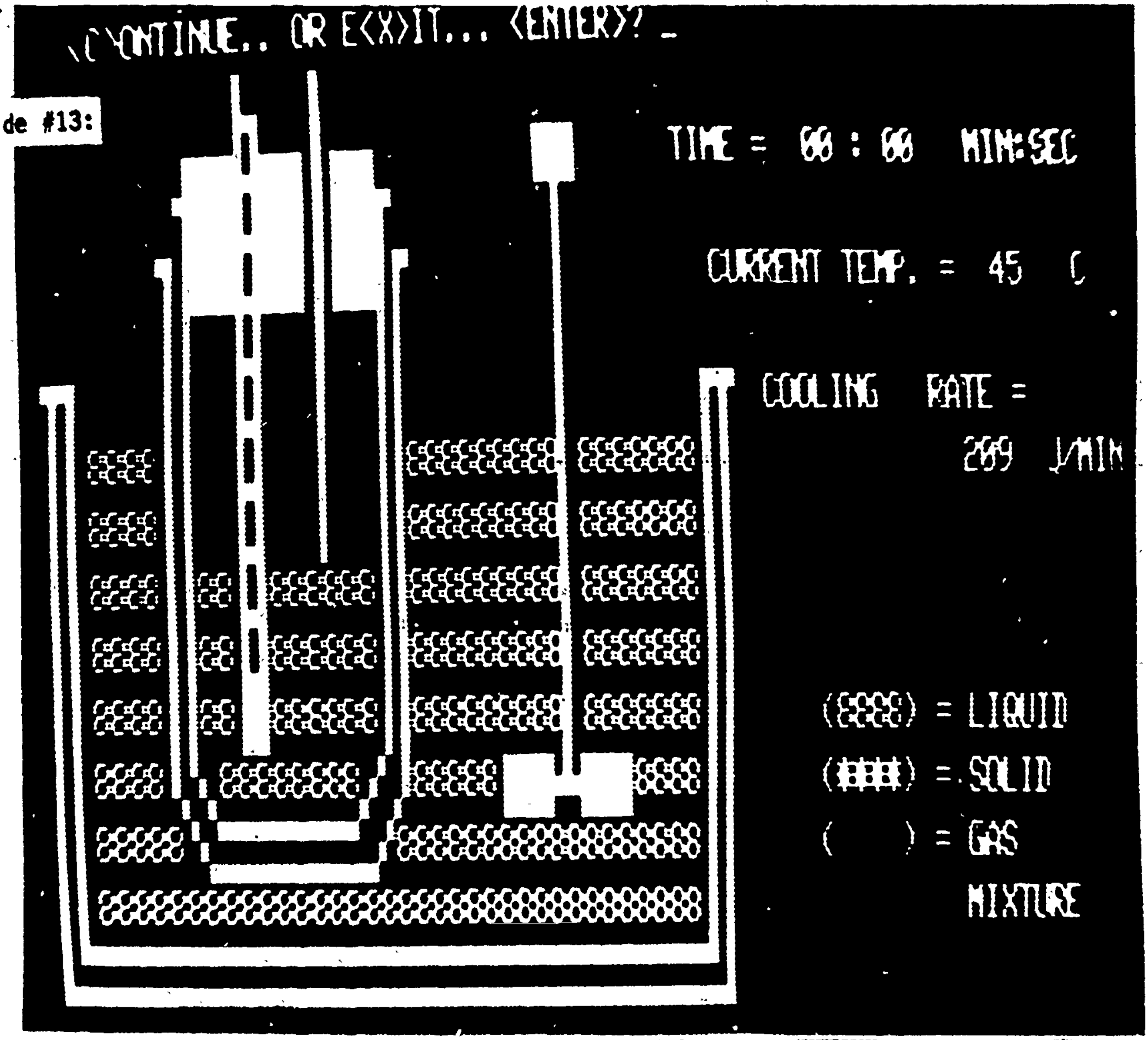
1. WHAT STARTING TEMPERATURE WOULD YOU LIKE?
2. DO YOU WANT TO ⟨HEAT⟩ OR ⟨COOL⟩?
3. WHAT ⟨ ⟩ RATE (SLOW, MODERATE, OR RAPID)?
4. WHICH TEMPERATURE RANGE (50^0, 100^0, OR 500^0)?

** SCREEN WILL STOP EVERY 15 SEC.

** YOUR SAMPLE IS IN THE DOUBLE TEST TUBE.

This slide shows an example from the melting-point experiment in which the initial conditions are established by these four parameters. If an error is made in any of these decisions the student is immediately informed. For instance, a starting temperature of minus 300° Celsius is greeted with an appropriate corrective feedback. An unproductive strategy such as heating a liquid is also greeted with a corrective statement and the student begins again. Two cues are given to focus attention on the sample position inside the test tube and the time interval for data points.

Slide #13:



When a student is first shown this graphic display, he needs time just to take in all the visual information. This wait-time interval may take anywhere from 15 seconds to one minute depending on the complexity of the display. The prompt or cue that tells the student what decision he must make should only appear after he has time to examine the display. Make the cue stand out by flashing it on and off several times after the wait-time interval. In general, first show the graphics then the cue.

Slide #14:

DECISIONS IN EMPIRICAL MODE

4. WHAT INFORMATION DO I RECORD?

5. WHEN DO I STOP?

Once into the experiment the relevant features and variables should be observed and recorded on a data sheet. Knowing when enough data has been collected is also necessary. The program must provide the answers to these questions in some easily recognized form.

Slide #15:

EMPIRICAL MODE (CONTINUED) ...

6. WHAT IS THE ... (RELEVANT VARIABLES)

(A) CURRENT TIME (MIN:SEC),

(B) CURRENT TEMPERATURE (^{0}C), AND

(C) PHYSICAL STATE (S, L, OR G)?

*OBSERVE MOTION OF SURROUNDINGS (EXTRANEOUS VARIABLES)

7. ⟨C⟩ CONTINUE, OR ⟨X⟩ EXIT?

Here is an example with the melting-point experiment. In this case the data sheet has a table column for each of these relevant variables so the student knows he should record them. The cue which says "to continue or exit" gives the student control of when to stop.

Slide #16:

DECISIONS IN GRAPHIC MODE

1. WHICH DATA DO I USE?
2. HOW DO I SHOW THE DATA?
   (A) SUMMARY TABLE
   (B) GRAPH
3. WHAT PATTERN DO I SEE?

The student has just collected a set of data. How is he to see a pattern in this data? Two typical ways of showing data in the sciences are summary tables and X- versus Y- type graphs. Once this is done the student can look for a particular pattern in his data.

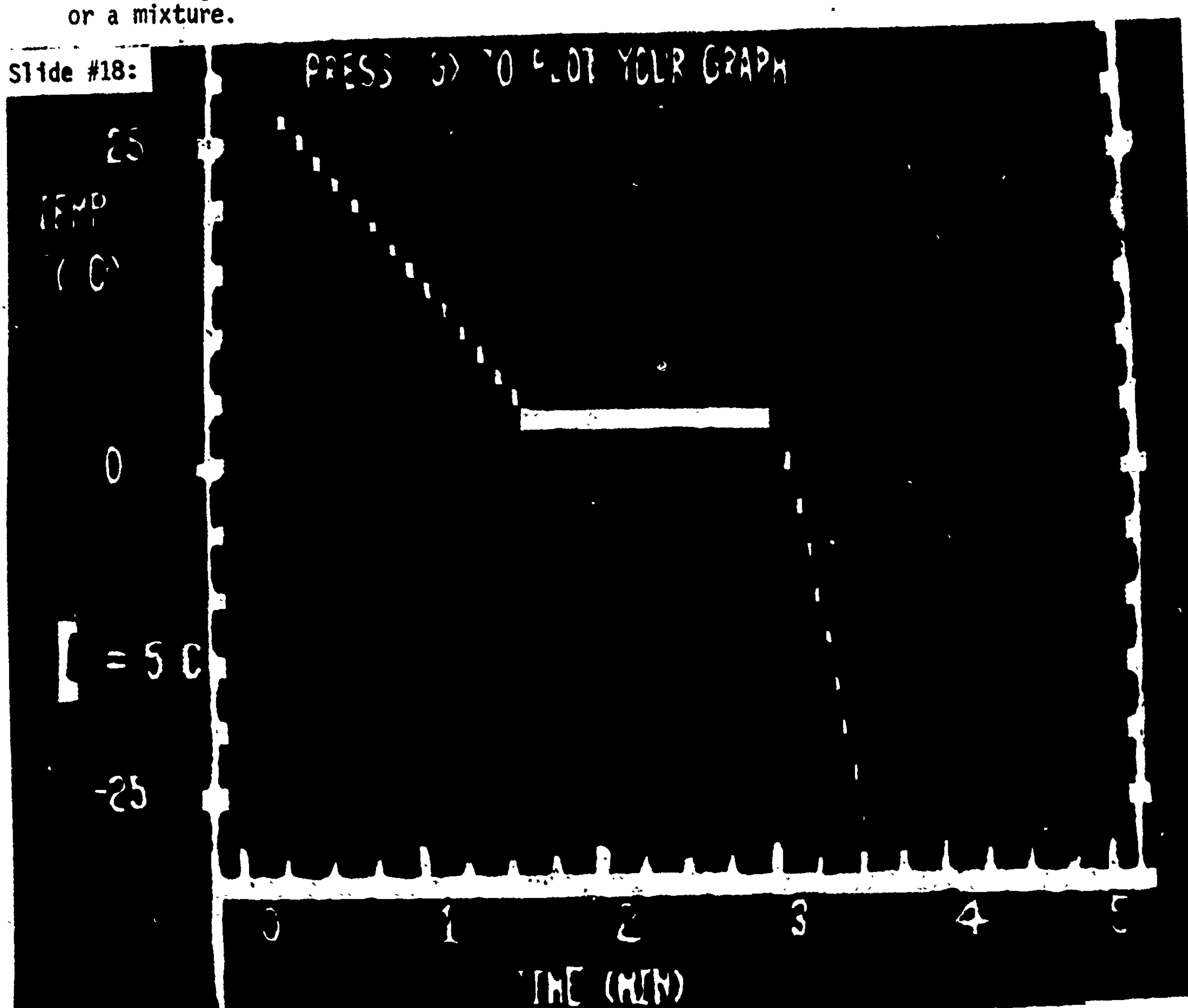
Slide #17:

Computer Lesson #1: Data Sheet

Time (Min:Sec)	Temp. (°C)	Physical State
00:00	30°	L
00:30	22°	L
01:00	13°	L
01:30	5°	L
02:00	4°	S,L
02:30	4°	S,L
03:00	4°	S,L
03:30	-25°	S

Here is an example of a summary table for the melting-point experiment. This set of data is all that is needed to accomplish the objective of determining whether a particular sample of matter is a pure substance or a mixture.

Slide #18:



Plotting the data on a X, Y graph lets us see a pattern in the data. After pressing "G", the student is given a cue which states "You should see three regions or slopes". The melting characteristic can then be inferred from the three slopes in this example.

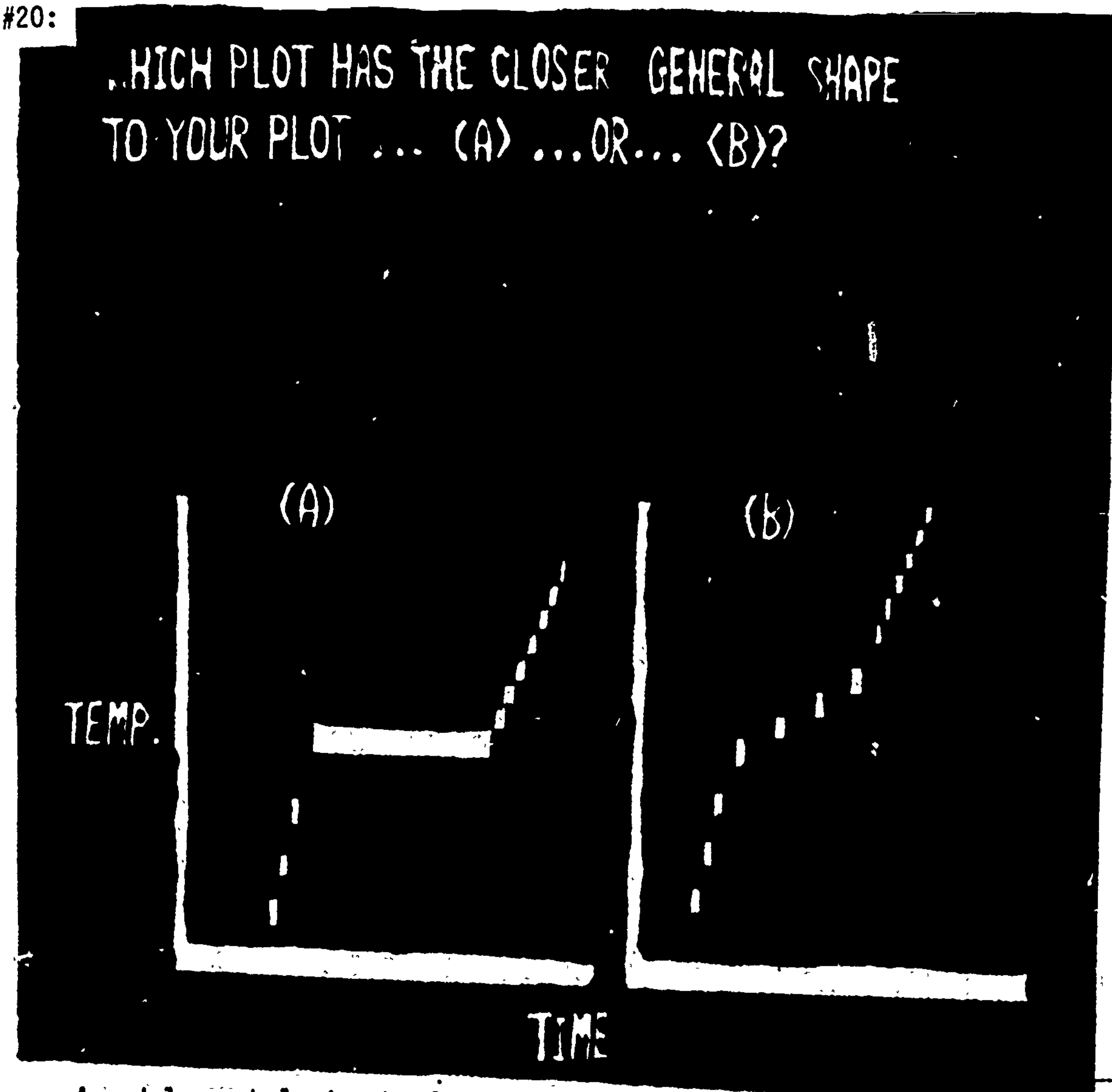
Slide #19:

DECISIONS IN SYMBOLIC MODE

1. HOW CAN I EXPRESS THIS PATTERN?
   - (A) VERBAL GENERALIZATION
   - (B) MATHEMATICAL RELATION
2. WHEN DOES THIS EXPRESSION APPLY?

It is not enough for the student to just see a pattern in his data. He must express the pattern in some generalized way. One possibility is a verbal generalization. For example, in a chemical kinetics experiment, the higher the temperature the faster the rate of reaction. Another type of expression is a mathematical relation, such as F = m * a in physics. The student should be given additional examples in which he applies the generalization. This shows him the limits and the set of appropriate conditions for a particular generalization.

Slide #20:



A model can help in the formulation or verbalization of the generalization. In the present case these two model curves can be used to distinguish the type of shape as being one with a flat portion in the middle or the other with no flat part. If we then tell the learner that "plot A" belongs to a pure substance then he can conclude that he has a pure substance. Note that the learner, not the program, does the comparison between shape of the sample plot to the shapes of the model curves.

Slide #21:

COMPUTER LESSON # 1: A PURE SUBSTANCE MELTS OR FREEZES AT A CONSTANT TEMPERATURE, WHEREAS A MIXTURE MELTS OR FREEZES OVER A RANGE OF TEMPERATURES.

We can now have the student state the generalization verbally. Thus he is guided to a discovery rather than being told it in lecture. He has used his own words to achieve this expression.

Slide #22:

MODES OF DECISION MAKING

1. PREPARATORY MODE
2. EMPIRICAL MODE -- ENCOUNTER PHENOMENON
3. GRAPHIC MODE -- ORGANIZE PHENOMENON
4. SYMBOLIC MODE -- MEANING OF PHENOMENON

In summary we have discussed four modes of decision making which occur in the process of a computer-simulated experiment. In this mode the student is given the problem and some major steps in its solution. He acquires certain skills and knowledge for the experiment. Next, in the empirical mode, he encounters the phenomenon and sees how a set of conditions affects his data. He then organizes this data in the graphic mode and attaches meaning to it in the symbolic mode. This is an inductive sequence in which the quest for knowledge is emphasized. Guidance is provided by cues and feedback at appropriate times. (We are analyzing data in which half the students use this inductive sequence and the other half use a deductive sequence in which the generalization is stated before the experiment is done.)

Slide #23:

COMPUTER-SIMULATED EXPERIMENT

CHEMICAL PRINCIPLES	MEANING
EMPIRICAL DECISION MAKING	ORGANIZE
CHEMICAL PHENOMENA	ENCOUNTER

In a computer-simulated experiment or other investigative process the decisions made in an experiment can organize the encounters made with a chemical phenomenon. This organization produces a pattern which is then expressed as a chemical principle. Now we have three levels of chemical knowledge each of which is connected in an explicit manner. Demonstrations done in lecture formerly fullfilled this organizing function. In spite of the merit of a demonstration, it takes up valuable lecture time. On the other hand, a computer-simulated experiment can be done outside of lecture time with each individual making decisions and seeing the results.

Slide #24:

TOPICS FOR COMPUTER-BASED LESSONS:

LESSON #	TOPIC
CL 1	PURE SUBSTANCES AND MIXTURES
CL 2	COMBINING VOLUMES OF GASES
CL 5	IONIZATION POTENTIALS
CL 6	THE NATURE OF COMPOUNDS
CL 9	IDENTIFICATION OF METALS
CL 10	COMBUSTION OF ORGANICS

We have used one simulated experiment as an example. This is the first one in a set of simulated experiments. This entire set of simulations has been used over several semesters with large classes at The University of Texas. They have also been used with smaller classes at a two-year college, Austin Community College.