Chapter 3

Six Gamelike/Experimental Microcomputer Simulations

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Introduction

A survey of the computer-assisted instruction (CAI) modules available for introductory college biology reveals an abundance of drill-and-practice modules, a smaller number of tutorials, and very few good simulations. The simulations which do exist are concentrated in population ecology, genetics, and enzyme kinetics. It is surprising that simulations are not more commonly used in the teaching of biology. They can allow students to perform difficult, dangerous, or expensive experiments without being hampered by logistics, low skill levels, or irrelevant distractions. They provide students with immediate feedback on the results of their actions and allow many experiments to be performed in the same time in which only one (or perhaps zero) experiments could be "wet-labbed." Simulations should not be used to replace feasible "wet" laboratory experiments, but they are a valuable tool for extending the range of experimental experiences which we give our students.

I have produced six diverse modules which attempt to implement these advantages. In most cases, the programs can be used both as experimental data generators, and as competitive games between teams of students. The modules have been included in the laboratory manual *More Biology in the Laboratory* by Doris and Carl Helms (Worth Publishers), but they are also available as individual packages.

It should be emphasized that in all cases, these modules are complex simulations, not tutorials. That is, they do not teach a few facets of a subject (such as plant physiology) "from the ground up." Instead, they devote most of available memory to presenting a realistic and flexible simulation which is capable of demonstrating many concepts. Indeed, it is easily possible that a creative user could think of uses for the programs which the author has not anticipated.

This is not to say that the programs are presented without explanation or suggestions. Each disk has a set of instruction screens which are directed at the student and which explain the operation of the program and the basic background biology needed to use it intelligently. In addition, the documentation includes an extensive Instructor's Guide, student exercises from *More Biology in the Laboratory*, and companion "wet" laboratory exercises. But the potential user should be aware that although these programs can be successful with average students, they require that the instructor adequately prepare the students.

The programs are listed below.

SEEDLING is a simulation of plant competition and plant physiology. The "experimental" mode of the program simulates the growth of a temperate zone, C3 crop plant in three different outdoor environments or in a growth chamber with constant, user-controlled conditions. Experiments on the effects of decreasing interplant distance, the responses of plants to different temperature and light conditions, and the influence of temperature and humidity on transpiration are included in the program. Each of these exercises takes 40–60 minutes; a student team would do only one exercise per laboratory.

The SEEDLING game allows users to manage a growing plant. The objective is to shade, dehydrate, and kill the plants which will be "growing" with their plant on the same computer. There are also random elements in SEEDLING: realistic but unpredictable weather for the three SEEDLING environments (western Texas, coastal South Carolina, and Puerto Rico), and attack by herbivores. When a plant dies, the program reports the cause of death. About 1 hour should be allotted for introducing and playing the SEEDLING game.

Although SEEDLING defines terms such as transpiration and net photosynthesis as it uses them, students will get more out of the program if they have this background when they first start using it. Also, the program uses a quantitative approach to plant physiology, reporting plant progress both in terms of plant measurements and in functional terms such as net photosynthesis in mg C fixed or lost per day. This can be intimidating to students. However, data for all plants is shown together. Thus even if a student cannot appreciate the absolute magnitude of (for example) a net photosynthesis result, it is still easy to compare the given result for his/her plant with previous results for the same plant or with the current results for the other plants. SEEDLING exercises require graphing, but neither the exercises nor the game require calculations.

ALIEN simulates the cardiopulmonary physiology of humans and five fictitious extraterrestrials who are adapted to exotic home planets. The user can perform experiments on the subject including exercise, changes in atmospheric P_{O2} and P_{CO2}, electric shock, and injections of acids, bases, tranquilizers, and stimulants. There are also more specialized experiments which allow computation of blood volume, cardiac output, stroke volume, and lung volume. The objective of the ALIEN game is to use these experiments to answer 16 physiological questions about the alien or human. The questions (about heart rate, blood pressure, metabolic rate, and heart performance under both resting and exercising conditions) require observations, calculations, and planning of an optimal sequence of experiments. The program grades accuracy of answers at the end, and the highest score in the class wins the game. Answering the questions should take about 1 hour.

The experiments in ALIEN are more elaborate and require further decisions from the students. For example, one experiment asks the students to explore the relationship between altitude and human running stamina. The students are told the partial pressure of oxygen corresponding to various altitudes, and how to determine the distance run before exhaustion, but the only advice on the altitudes to choose is that they must show the complete range of running distance response (e.g., from no degradation of performance to complete inability to exercise). Thus the students are involved in the design of the experiment.

In addition to the altitude/running stamina experiments, there are exercises on the effect of running speed on the distance run before exhaustion, physiological responses to exercise in both normal and reduced oxygen levels, and compensation for increasing atmospheric CO_2. Some of these exercises are as short as 10 minutes; the longest is the altitude/running exercise, which takes 60 minutes.

Like SEEDLING, ALIEN defines terms but does not teach extensive background. Thus students will derive the most benefit from it if they already are familiar with basic concepts such as the contrasting characteristics of arterial and venous blood, and gas partial pressures. Also, it requires that students use given formulae to calculate results. Most of the exercises require graphing skills. Of course, even students with deficient backgrounds can use the program as a "let's see what happens if..." experience. However, the instructor should expect that unsupervised students will concentrate on dramatic and usually lethal experiments (such as shocking the subject to death) and will not make very systematic observations.

Exercise A of ALIEN (page 33) is presented here to serve as a sample of the type of laboratory exercises which are available for all of the programs.

PLANKTON simulates the seasonal mixing cycle of a lake and the ecology of lake phytoplankton. The experimental mode of PLANKTON asks the students to manipulate temperature, light, nutrients, and grazing pressure to determine the factor which is most limiting to a phytoplankton population. The single condition improvement which causes the largest increase in the population growth rate shows the most critical limiting factor. A second experiment detects possible synergism between two or more limiting factors.

The user may select lakes in Wisconsin, South Carolina, or Puerto Rico, do the experiment in spring, summer or fall, and use a lake which is oligotrophic, eutrophic, or hypereutrophic. In addition, the student may choose 10 depths from which to take the tested phytoplankton population. Needless to say, the experimental results for a bottom population of a tropical lake may be quite different from the results for a surface population of a Wisconsin lake. Thus there is no simple a priori "right answer" for the limiting factor. PLANKTON's experiments are a good antidote for the student tendency to ignore the experiment and simply put the well-known correct answer in the blank space in their laboratory manuals. Both the single-factor experiments and the two-factor synergism experiments take about 30 minutes each.

In the PLANKTON game, each user controls a population of phytoplankters, and attempts to maximize the population's reproductive rate by migration to the optimum depth within the water column. If a population falls below a certain percentage of the total of all the populations, its plankters are killed.

PLANKTON is demanding for two reasons. First, the content (lake stratification and mixing regimes, depletion of nutrients from the water by phytoplankton, grazing by zooplankton, etc.) is unfamiliar to most students (and instructors). Second, although the concept of a controlled experiment is taught universally, on their first attempt with PLANKTON few students seem to understand why one would want to bring only one factor (light, temperature, nutrients, or grazing) to its optimum while keeping the others at their environmental values. Their tendency is to vary all factors simultaneously and unsystematically. However, since this concept of a controlled experiment is a valuable lesson and can easily be reinforced by repeated PLANKTON experiments in different environments, it is worth the expenditure of class time to give students the background and then drill them on application.

CYCLE is a simulation of the menstrual cycle, human fertility, and pregnancy. In the CYCLE game, students try to predict the fertile periods of a simulated woman with variable cycle lengths. Accurate predictions win them game points. But if they predict infertility too close to ovulation, they start a pregnancy and incur a massive point penalty. The game can be played on difficulty levels ranging from easy (data on hormones, basal body temperature, follicle diameter, uterine lining, and menstrual flow all shown) to difficult (only menstrual flow shown). One use of CYCLE which excites much student interest is to zero the scores on all computers and then hold a 5 minute competition between student teams. Ambitious teams will tend to play on the riskiest level, and frequent pregnancies and reversals of team fortunes will cause much hilarity. About 60 minutes should be budgeted for introduction and playing of CYCLE.

CYCLE also allows the user to change the secretion rate of estrogen, progesterone, FSH, and LH to multiples of the normal values and to observe the effects on the other hormones or on pregnancy. The most common experiment is to demonstrate the effect of birth control pills. This demonstration takes about 10 minutes.

SHARK puts users in control of a bonnethead shark which is searching for prey off the coast of South Carolina. The user detects and homes in on prey by using a non-visual "instrument panel" which reports the magnitude of olfactory, acoustic, and electrical signals being received on both sides of the body.

To win points, the shark must swim down a signal gradient and accurately attack a prey (which may be moving, and will try to escape if alerted). But some prey are too fast or too dangerous to attack, so knowledge of the forty species of prey items and their habitats (provided in the Instructor's Guide) is essential. A more ominous problem is that large, fast sandbar sharks and tiger sharks are prowling the offshore waters, ready to attack careless bonnetheads. SHARK includes several different habitats, each with its own topography and fauna: the offshore sand, offshore and inshore rocky outcrops, sandy beach, estuarine mud flats, and salt marsh. Thus the program teaches offshore geography as well as non-visual predation and the ecology of common coastal animals.

In the SHARK point system, the points awarded for killing a prey item are proportional to the number of kilocalories which the prey contains. Injury reduces the shark's score, and a certain cumulative injury will kill it no matter how many points it has accumulated. Thus the shark must seek out harmless prey which are as large as possible and avoid serious injury. The students are also given a choice of three difficulty levels. As the difficulty levels rise, kills are rewarded with more points, but the prey become more elusive and more accurate attacks are necessary.

SHARK may either be used as a game or as an optimal foraging exercise. In the game, students are urged to gain skill at attacking prey and then follow whatever strategy seems most productive in attaining the maximum number of points. A zeroing of scores followed by a 15 minute competition for the highest score will result in a high level of student interest. About 60 minutes is necessary for a successful SHARK game, although some instructors have used SHARK for 1 hour a day for several consecutive days. Students may then write a report on the success of failure of their foraging strategy or on other aspects of non-visual predation, coastal marine ecology, or predator-prey relations.

SHARK is most successful as a game, but if desired the instructor may use it as an experiment in optimal foraging. Optimal foraging theory is a branch of ecology which attempts to determine if natural selection has optimized the diet choices and foraging methods of animals. In SHARK, the student is asked to compose a *simple* set of foraging rules which would maximize the point gain of a shark (e.g., always attack whatever prey item is closest). Different teams compose different rules, and then each team follows its rules for about 30 minutes. The relative success of the different foraging rules can be determined from the scores the teams attain.

DUELING ALLELES, a population genetics simulation, is somewhat simpler than the other programs. The program simulates the changes in frequency of the *b* allele which are caused by drift and selection. The student may vary the population size (from 1 to 50 mating pairs) and the probability that genotype *BB*, *Bb*, and *bb* will die before reproduction. Each generation the program plots the frequency of *b* and the number of organisms of each genotype until the *b* allele either becomes extinct or attains a frequency of 1.0. Every simulation gives different results because both organism death and mating are driven by a random number generator.

Exercises are provided on the effects of population size, heterozygote advantage, and recessiveness on the persistence of a deleterious allele. Each of these exercises takes about 10 minutes.

Materials

Program Documentation

Each program package includes the following:

1. One diskette, either Apple-compatible or IBM-compatible.

2. One or more student exercises, including both background and consumable worksheets. The student exercises are extracts from *More Biology in the Laboratory* by Doris R. and Carl W. Helms (Worth Publishers, Inc., New York, 1989, $24.95 US).

3. An Instructor's Guide, which contains a detailed program description, more extensive background than given in the student exercises, instructor discussion guides to the student exercises, pedagogical advice, handout masters, and transparency masters.

4. A set of companion "wet" laboratory exercises which reinforce the lessons of the computer exercises.

All of the programs (sold under the name "BioBytes") may be ordered from Worth Publishers, Inc., 33 Irving Place, New York, NY 10003, (212) 475-6000. Each program is available individually at a cost of $30.00 US per program. All six programs are available as one package at a total cost of $100.00 US. Users are permitted local copying of the programs in one institution (i.e., copying a program for use on each computer in your classroom).

Hardware Requirements

The Apple versions of the programs require an Apple //e or Apple IIGS with at least 64K of RAM and one floppy disk drive. Color monitors or 80-column graphic cards are not required. The IBM versions were written for an IBM PC or PC-XT with at least 256K, one floppy disk drive and a graphics card (either color or Hercules-compatible monochrome). They can also be used on IBM PS/2 and on IBM-compatible computers, although there might be some abnormal operation in some cases. The Instructor's Guide which comes with each package explains the IBM compatibility situation in detail.

Because the programs (especially the Apple versions) access the diskette from time to time, each computer must have a program diskette loaded in its disk drive. Ideally, there should be one computer per group of three to four students and the instructor should circulate through the room in order to provide advice and encouragement. Because of its large graphics, CYCLE can be used successfully as an instructor demonstration. But in the cases of the other programs, the best alternative if the total number of computers is low is to allow small groups of students to take turns using the computers. Each student should have a copy of the student exercise and there should be one copy of each handout at each computer.

Sample Student Exercise for ALIEN

ALIEN is a computer simulation of heart-lung physiology. It may be used as either a game or as a data generator. In the game, you will assume the role of a cardiopulmonary physiologist whom NASA has hired to experiment on the first extraterrestrial to be brought back to Earth (thus the title—ALIEN). The program simulates five imaginary aliens with physiologies quite different from the human, but which are well adapted to their home planets. It also simulates the physiology of a human "volunteer" (a pre-med student) on whom you can practice before performing experiments on the valuable aliens. The experiments include exercise, changing the oxygen or CO_2 content of the atmosphere, injecting drugs, and administering electric shocks.

As you put the aliens or the human under stress they will increase their heart rate, blood pressure, and ventilation rate, and if you push them too far they will drop from fatigue, faint, have a heart attack, and finally die (if not saved in time by cardiopulmonary resuscitation—CPR).

The game objective is to determine the answers to 16 physiological questions about the human or alien. Your score is assigned depending on the accuracy of your answers. Different student teams within the laboratory section may compete for the highest score.

ALIEN can also be used to generate data for two sets of simulated experiments. In the first set (Exercise A, the "demonstration experiments"), you will follow directions in this manual and record your observations. In the second set (Exercises B and C, the "student-planned experiments"), you will be given background information on the experiment but you will plan the experimental treatments yourself.

During the laboratory period, you will perform Exercise A , *one* of two student-planned experiments (either Exercise B or C), and, if time permits, you will attempt to answer the questions provided (Exercise D).

Using ALIEN

ALIEN displays several complex physiological variables, and you may not be familiar with all of them. Therefore, before starting the exercises, it would be worthwhile to review the program's screens and to explain the displayed variables.

ALIEN begins with introductory screens. You will be asked whether you prefer to use a human or one of the five aliens. After a summary of the conditions on the subject's home planet, the program proceeds to the "digital display screen." This is different on the Apple and IBM versions of ALIEN. The Apple digital display screen for a resting human is shown in Figure 3.1. The IBM digital display screen for a resting human is shown in Figure 3.2.

Both the Apple and IBM displays are divided into an upper portion which gives the values of physiological variables such as heart rate, and a lower portion which gives the control keys by which the user can administer experiments such as exercise or a change in oxygen partial pressure. An explanation of each of the control keys ("A B C ....") is given in Table 3.1 (pressing the "?" key will also give you this information).

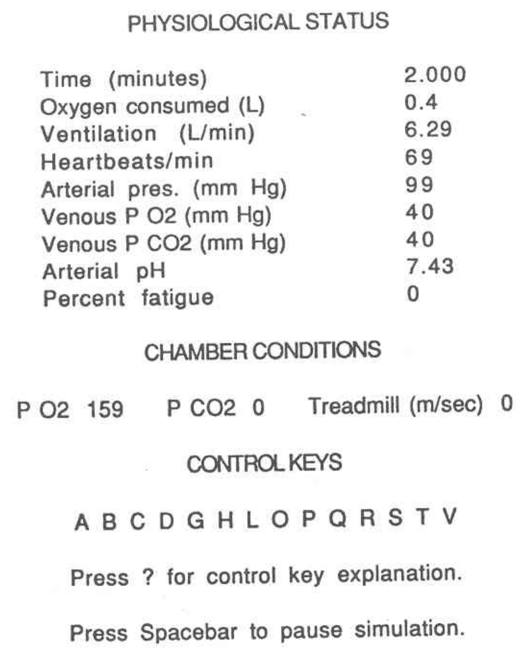

Figure 3.1. The Apple digital display, showing the control keys and the values of physiological variables for a resting human.

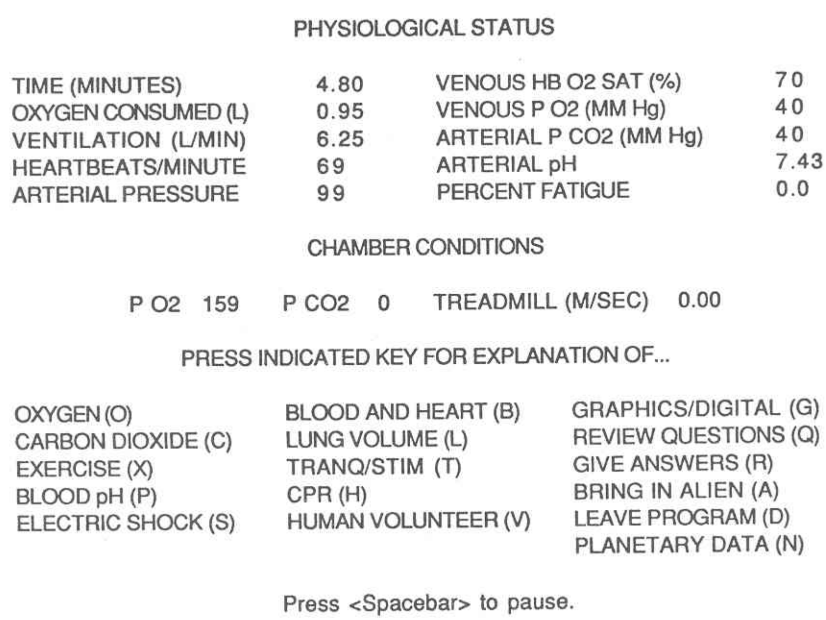

Figure 3.2. The IBM digital display, showing the control keys and the values of physiological variables for a resting human.

Table 3.1. Control keys used in ALIEN.

Spacebar	Pause the simulation
A	Bring in a fresh alien or human volunteer
B	Compute blood volume, cardiac output and stroke volume
C	Vary the carbon dioxide partial pressure in the chamber
D	Exit the program, with an option to save the game
G	Switch from digital display to graphic display, and vice versa
H	Administer CPR and artificial respiration
L	Compute total lung volume
N	View normal conditions on subject's home planet
O	Vary the oxygen partial pressure in the chamber
P	Change the pH of the blood by injecting acid or base
Q	View a list of the sixteen questions
R	Answer the questions
S	Administer an electric shock to the subject
T	Inject tranquilizers or stimulants
V	Bring in a fresh **human** volunteer (works only if the current subject is a human)
X	Exercise the subject on a treadmill

The ALIEN Graphic Displays

The graphic displays are accessed by pressing the "G" key. Pressing the "G" key again returns the user to the digital display. Because of the large size of the ALIEN program, the Apple graphics display uses only low resolution graphics. The tic marks along the sides of the bars represent multiples of the resting values. Therefore the lowest tic mark is the resting value. The graphic display screen for a jogging human is shown in Figure 3.3

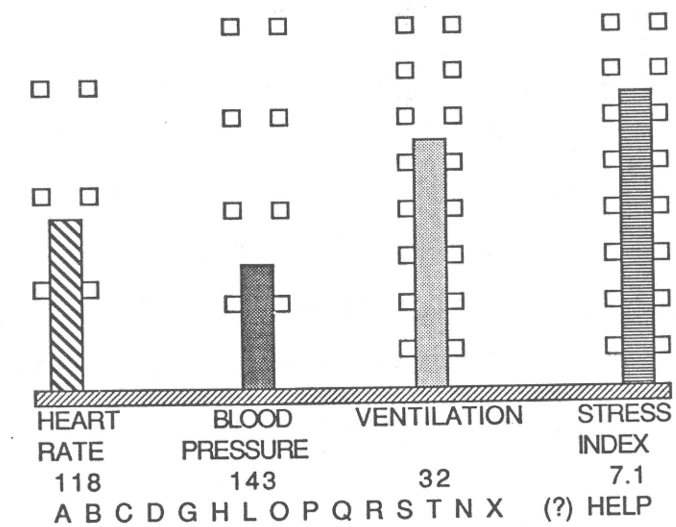

Figure 3.3. The Apple graphic display, showing a plot of four physiological variables for a jogging human.

The IBM graphics display presents a plot of the same four variables for about 2 minutes into the past (*not shown*). Again, the tic marks are multiples of the resting values. Values greater than 8× resting are off-scale in both displays.

The Variables Displayed on the Digital Screen

Time (minutes) is cumulative time since the beginning of the session. ALIEN game time runs slightly more slowly than real clock time.

Oxygen Consumed (liters) is also cumulative since the beginning of the session. At one point you will be asked to compute oxygen consumption rate, and remember that you must use the *change* in oxygen consumed divided by the *change* in time.

Ventilation Rate (liters/minute) is the rate at which air is moving in and out of the lungs. It is not the same as oxygen consumption rate.

Heart Rate (beats/minute) is the same as the pulse rate.

Blood Pressure (mm Hg) is expressed as the height of a column of mercury that the blood pressure would support. Blood pressure in a resting human rises to a peak of about 120 mm Hg when the heart is contracting and falls to 80 mm Hg when the heart is relaxed. ALIEN averages these into a single value of 100 mm Hg for the human.

Oxygen Saturation of Venous Hemoglobin (percent). This is only displayed in the IBM version, and shows the percentage of venous hemoglobin which is saturated with oxygen (70% for a resting human, but 20% in violent exercise).

Partial Pressure of Oxygen (P_{O2}) in the Venous Blood (mm Hg). Partial pressure is a measure of oxygen concentration in the air or in a tissue. P_{O2} is 159 mm Hg in air, about 100 mm Hg in the alveoli of the lungs, and 40 mm Hg in the tissues. In violent exercise the tissue value may drop to 20 mm Hg, and unconsciousness will occur if it drops to 10 mm Hg.

Partial Pressure of Carbon Dioxide (P_{CO2}) in the Venous Blood (mm Hg). In humans, even small increases in P_{CO2} above the resting value of 40 mm Hg will result in frantic hyperventilation.

Arterial pH. The normal human arterial pH is 7.4. Excess CO_2 or anaerobic respiration by fatiguing muscles lowers the pH; blowing off CO_2 during hyperventilation raises the pH.

Percent Fatigue is an arbitrary index; 100% fatigue causes collapse from exhaustion. Fatigue increases only during exercise, and decays away during periods of rest.

Stress Index is an index indicating excitement. In humans, a stress index of 45 results in cardiac arrest.

Exercise A

In Exercise A, you will force a human to run to exhaustion at sea level, run a human to exhaustion (and probably death) at high altitude, and observe a human's attempt to compensate for increasing amounts of CO_2 in the atmosphere. The demonstration experiments rapidly illustrate some of the more dramatic and important features of ALIEN.

The cardiopulmonary system is a mechanism for maintaining homeostasis in spite of stress. Vigorous exercise is one of the greatest stresses the body must withstand, but the success of homeostasis is shown by the body's ability to compensate for it. At rest, the oxygen consumption rate is about 0.2 liters/minute; during exertion consumption may rise to 20 times this amount. It might be expected that such massive increases in oxygen demand might cause oxygen to disappear from the tissues within seconds. Yet oxygen in venous blood only drops from 40 mm Hg to about 20–30 mm Hg. Carbon dioxide in the arterial blood rises only slightly, from 40 to 45 mm Hg, and if the exercise is prolonged it returns to the resting value or even lower. This homeostasis is possible because of the compensation of the cardiovascular system and the lungs.

Essentially, increased CO_2 in the arterial blood causes a rapid increase in ventilation. This brings the CO_2 in the lungs to a very low value, and establishes a steep diffusion gradient from the venous blood to the alveolar air. At the same time, rapid blood flow purges CO_2 from the tissues and brings in large supplies of oxygen. Eventually, however, fatigue causes collapse and the changes which exercise brought about are gradually reversed as the subject recovers.

The homeostatic system cannot operate so successfully at high altitude (the oxygen equivalent of 9000 m, almost 30,000 ft). At this altitude, there is only one third of the normal amount of oxygen in the air. No matter how fast the lungs ventilate and the blood flows, the system cannot deliver enough oxygen to the tissues. Venous oxygen dips below the lethal level (5 mm Hg) and cardiac arrest occurs. With no blood flow and no ventilation, venous P_{O2} drops even faster and soon there is no oxygen in the venous blood. Meanwhile, arterial CO_2 rises rapidly, and brain death occurs within a game minute.

The increasing carbon dioxide exercise shows again how the cardiovascular system and the lungs are a marvelous device for maintaining homeostasis, but how the system will collapse if it is pushed beyond its ability to compensate. As moderate amounts of CO_2 are added to the atmosphere, the subject can easily compensate by increasing his ventilation rate. Large increases in atmospheric CO_2 cause only minor increases in arterial CO_2. But eventually the subject is breathing as fast as he can, and no more compensation is possible. After this point, further increases in atmospheric CO_2 cause equal increases in arterial CO_2, and soon the respiratory center in the brain becomes depressed and death follows.

Objectives

1. Determine the changes in metabolic rate, ventilation rate, heart rate, and blood pressure which accompany exercise at sea level.

2. Explain how the body compensates for the stress of exercise at sea level.

3. Describe how a low-oxygen atmosphere disrupts the exercise homeostasis which can be maintained under normal oxygen conditions.

4. Describe how the body compensates for increasing concentrations of carbon dioxide in the air, and how this homeostasis breaks down if the carbon dioxide concentration gets too high.

Procedures: Part 1

1. Insert the ALIEN diskette in the diskette drive and turn the computer and monitor on.

2. Indicate that you do *not* need instructions.

3. Choose a human as your subject.

4. When the digital display screen is displayed, wait a few seconds and then press the spacebar to pause the simulation. Fill in the first column of Table 3.2 with the resting values of heart rate, ventilation rate, arterial CO_2, and venous oxygen.

5. Start the simulation again by pressing the spacebar. Then press the "X" key and quickly raise the treadmill speed to 8 meters/second (a 3.4-minute mile).

6. Using both the digital and the graphic displays, watch the trends in heart rate, ventilation rate, etc. as the subject runs to exhaustion. If you need to pause the simulation, do so by pressing the spacebar. Watch the "Percent fatigue" variable, because when it reaches 100% the subject will drop from exhaustion. *Just before the subject drops from exhaustion,* record the values in the second column of Table 3.2. You may pause the simulation to do this.

7. When the subject does drop, note the game time. At 0.5 and 1.0 game minutes after collapse, record the values in the third and forth columns in Table 3.2.

Table 3.2. Response of human subject to exercise at sea level (oxygen 159 mm Hg). Data are taken before exercise, at the moment subject drops from exhaustion, and 0.5 and 1.0 minutes after dropping from exhaustion.

	Resting	Exhaus.	0.5 min.	1.0 min.
Heart Rate				
Ventilation				
Arterial CO_2				
Arterial pH				
Venous Oxygen				

8. Answer the following questions:

   a) Why does ventilation rate go up as the subject exercises?

   b) Why is it helpful for homeostasis that heart rate and blood pressure rise drastically during exercise?

   c) What evidence do you see that homeostasis of blood gases is being maintained despite the stress of exercise?

   d) Which is the first variable mentioned in Table 3.2 which returns to normal values? Why do you think this variable is first?

   e) Why do all the variables in Table 3.2 gradually return to their resting values? Why does recovery occur once exercise stops?

Procedures: Part 2

1. Press the "V" key to discard the fatigued human subject and bring in a fresh one. Pause the simulation after it has been running a few seconds and record the values in the first column of Table 3.3.

2. Press the "O" key and lower the oxygen from 159 mm Hg to about 50 mm Hg (about the same oxygen as would be present at the top of Mt. Everest).

3. Press the "X" key and raise the treadmill speed to 8 meters/second.

Table 3.3. Response of human subject to exercise at 9000 meters (oxygen 50 mm Hg). Data are taken before exercise, at the moment the subject becomes unconscious, when arterial P_{O2} reaches 5 mm Hg, and when arterial P_{O2} reaches 0 mm Hg.

	Resting	Uncon.	Art. Po_2 5mm Hg	Art. Po_2 0 mm Hg
Heart Rate				
Ventilation				
Arterial CO_2				
Arterial pH				
Venous Oxygen				

4. This time watch venous oxygen, which will go much lower than in Part 1. When the subject goes unconscious, immediately pause the simulation and record the values in the second column of Table 3.3. Then unpause the program and continue watching venous oxygen.

5. When venous oxygen reaches 5 mm Hg, record the values in the third column in Table 3.3. Finally, when venous oxygen reaches 0 mm Hg, record the values in the fourth column.

6. Continue to note the change in arterial CO_2 until the subject dies.

7. Answer the following questions:

   a) Why did exercise cause a failure of homeostasis in this case? What was different from the situation in Part 1?

   b) Why did arterial CO_2 remain at fairly normal values until cardiac arrest, but then rapidly increase?

   c) In ALIEN, reducing oxygen partial pressure from 159 mm Hg to 50 mm Hg does not change the partial pressure of the other gases. That is, total atmospheric pressure only declined from 760 mm Hg to 651 mm Hg. How do you think the result of the simulation would have been different if the program had really simulated an increase in altitude and *all* gases had declined to the same degree as oxygen (total atmospheric pressure declining from 760 mm Hg to 239 mm Hg)?

Procedures: Part 3

1. Bring in a fresh human subject. Pause the simulation after it has been running a few seconds and record the values in the first column of Table 3.4.

Table 3.4. Response of human subject to increasing partial pressures of CO_2. The values in the table are those at which the subject stabilizes after 15–20 seconds at the P_{CO2} indicated.

	0 mm	30 mm	60 mm	120 mm
Ventilation				
Arterial CO_2				
Arterial pH				

2. Press the "C" key and raise the CO_2 to 30 mm Hg. Note how arterial CO_2 and ventilation rise briefly, but then rapidly settle down to a new equilibrium. Record the values in the second column in Table 3.4.

3. Raise the CO_2 to 60 mm Hg. Again note the surge in arterial CO_2 and ventilation. Record the values in the third column in Table 3.4.

4. Finally, change the atmospheric CO_2 to 120 mm Hg. Note the trends in arterial CO_2 and ventilation, which will be different than in the cases above. Cardiac arrest will soon occur. When it does, pause the simulation and record the values in the fourth column in Table 3.4. There is no need to rush, since the subject has abundant venous oxygen and is in no danger of dying immediately.

5. Use CPR to save this abused human:
   a) Bring atmospheric CO_2 back to 0 mm Hg.
   b) Press "H" for CPR.
   c) Press "S" to start heart massage.
   d) Press "V" and set the respirator at a 15 liters/minute ventilation rate.
   e) When the subject's heart starts again, press "Z" to take him off CPR. As you do, note how ventilation surges to life and how CO_2 is rapidly blown off and normal conditions are restored.

6. Answer the following questions:

   a) The success of homeostasis can be measured by the *difference* the system can maintain between the atmospheric CO_2 and the arterial CO_2. That is, there would be no homeostasis if arterial and atmospheric CO_2 were always equal; there would be perfect homeostasis if arterial CO_2 always remained constant despite all changes in atmospheric CO_2. What evidence do you have that the human system can maintain homeostasis at 30 mm Hg of atmospheric CO_2?

   b) *How* is homeostasis maintained at 30 mm Hg of CO_2?

c) Is homeostasis less effective at 60 mm Hg of CO_2? Why?

d) Why does the system break down at 120 mm Hg of CO_2?