

Four Sample Lesson Plans

Translated from German

translated and adapted by
Stephanie Albin
MIT Class '98
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1 Keefe Road
Acton, MA 01720

Under the Supervision of
Dr. Jay W. Forrester
System Dynamics in Education Project
Sloan School of Management
Massachusetts Institute of Technology

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These lesson plans were sent to Nan Lux at the System Dynamics Group, MIT, Cambridge, Massachusetts in the Spring, 1995 by the following person. Please feel free to reach him directly with comments or for further direct contact.

Hans-Ulrich Doenhoff
OStR Dipl.-Phys.
Schillerstr. 11
D-58452 Witten, GERMANY

Phone: 02302-26997

Email: doenhoff@lsw-soest.nw.schule.de

The examples in this paper were built using the STELLA II¹ software package. The exercises require STELLA or a similar modeling package. If you have a Macintosh² computer, you need 2 Mb of RAM if running System 6.0.4 and at least 4 Mb of Ram if running system 7 or higher. If you have an IBM compatible, you must be running Windows³ and have at least 4Mb of Ram.

If you do not have STELLA, or wish to upgrade to a newer version, the software can be obtained from High Performance Systems:

High Performance Systems, Inc.
45 Lyme Road
Hanover, NH 03755
(800) 332 - 1202

If you would like to receive these 4 models already built in STELLA, please contact Nan Lux at nlux@mit.edu with your request and postal address.

Please note that these lesson plans were developed independently from the MIT System Dynamics Education Project.

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1. Introduction

This paper intends to serve as a guide for teachers to help them implement system dynamics in their lesson plans. The four examples discussed are based on four German lesson plans. These lessons cover a wide range of topics from population demographics, titration, algae, and finance, and are geared toward a middle school and high school audience. The system dynamics implementation examples and models are not meant to be complete lesson plans. Hopefully they will serve as an inspiration and a guide.

By using system dynamics and computers together in the classroom, students not only learn the curricula but also learn about information and communication technology. The 5 step modeling process to be followed by students as described in one paper⁴ is:

- 1) Analyze real situations using news clips, brochures , political cartoons.
- 2) Construct qualitative model from the given data.
- 3) Construct a quantitative model using System Dynamics modeling software.
- 4) Experiment with the model.
- 5) See how the model compares with reality.

⁴ ICH KAUF MIR WAS! VOM ERSPARTEN ODER AUF PUMP?

2. Lesson One: To Spend or to Save? Personal Finance

ICH KAUF MIR WAS! VOM ERSPARTEN ODER AUF PUMP?

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Paradieser Weg 64

59494 Soest

Germany

adapted by: Michael Klein

conception: Michael Klein

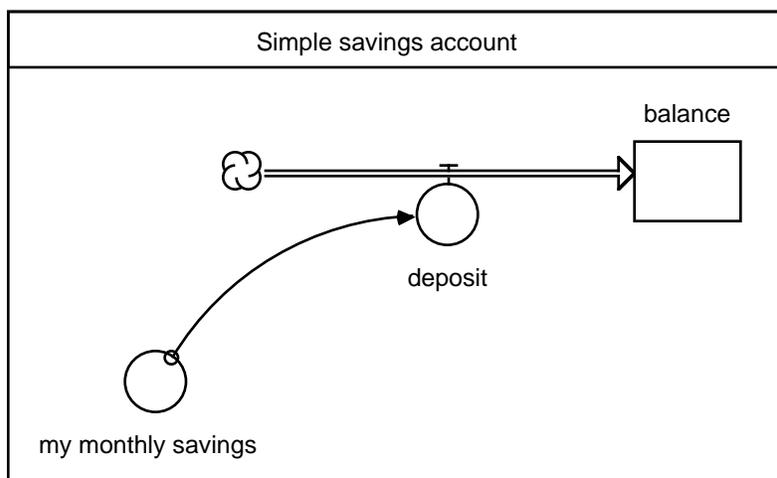
Philipp Portscheller

editorial staff: Michael Klein, Landesinstitut für Schule und
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1995

The goal of this lesson plan is for students to interpret news articles and graphs, use math, and then build models of savings and repayment for financing consumer goods. Typical homework assignments which incorporate system dynamics are:

1) The diagram below shows a model of a simple savings process. Describe the model in your own words. Find examples out of your everyday life where the model would apply.



Model 1

MODEL 1 DOCUMENTATION

$$\text{balance}(t) = \text{balance}(t - dt) + (\text{deposit}) * dt$$

$$\text{INIT balance} = 0$$

INFLOWS:

deposit = my monthly savings

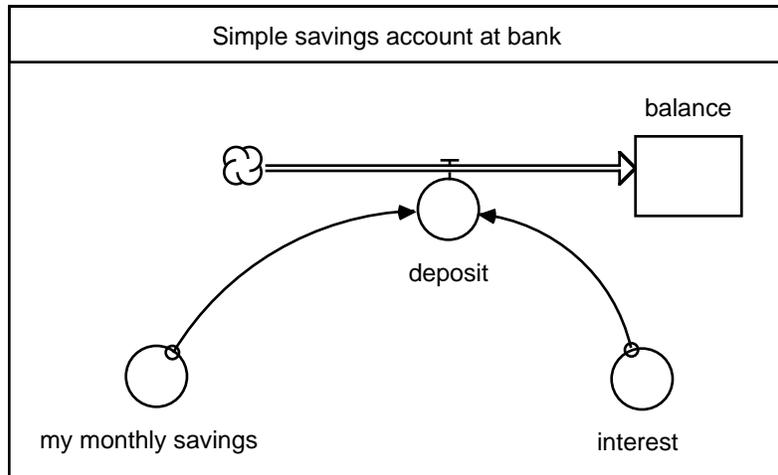
my monthly savings = 15

2) How long would you have to save to buy something you want? First, make a guess. Then compute it yourself, using the table below. Next, build the above model and compare your answer to the computer simulation.

Time (months)	Balance	Monthly Savings
0	Starting Value:	Savings for the next month:
1		
2		
3		
4		
5		

3) (Instructors should distribute 3 or 4 advertisements from a newspaper, depicting electronic goods (TV or VCR...) with the current price as well as a monthly installment price) Examine the ads from various stores. Which is better, paying the full price or paying under the installment plan? Build a model to prove this. Give further reasons for and against each option.

4) Describe the following model of savings in a bank. Is it correct? Why or why not? Build the model on the computer and add the converter "interest rate" to the model.



Model 2

MODEL 2 DOCUMENTATION

$$\text{balance}(t) = \text{balance}(t - dt) + (\text{deposit}) * dt$$

$$\text{INIT balance} = 0$$

INFLOWS:

$$\text{deposit} = \text{my monthly savings} + \text{interest}$$

$$\text{interest} = 1$$

$$\text{my monthly savings} = 15$$

Assume you deposit a large sum you received for your birthday at 3% and add no further money. How long would it take to save up enough to buy an item you would like?

5) Assume you get \$150 dollars from your grandparents every year on your birthday. Add that structure into the model.

6) Build a model showing the following process: Your parents borrow money from the bank. Each month they repay part of the loan. The bank charges interest.

7) (This example should be accompanied by a bank brochure describing a variable interest rate.) What is a variable interest rate? How would it effect your parents, if they took out a loan? As a class, build a model incorporating a variable interest rate.

8) Small project ideas:

Collect newspaper and magazine ads geared towards youth. How do they try to convince teenagers to buy their products? Where do you look to find out what's new? Make your own ad and have a class exhibition.

Analyze the following question: How much money do kids need to spend to be "in"? Where do they get their money? Why is it important to have these new things? Interview another student. Have a role-playing exercise in which a student is asking a parent for money to buy something new.

3. Lesson Two: Population Demographics

DEMOGAPHIA

distributor: Landesinstitut für Schule und Weiterbildung
Paradieser Weg 64
59494 Soest
Germany

adapted by: Philipp Portscheller

conception: Michael Klein
Philipp Portscheller

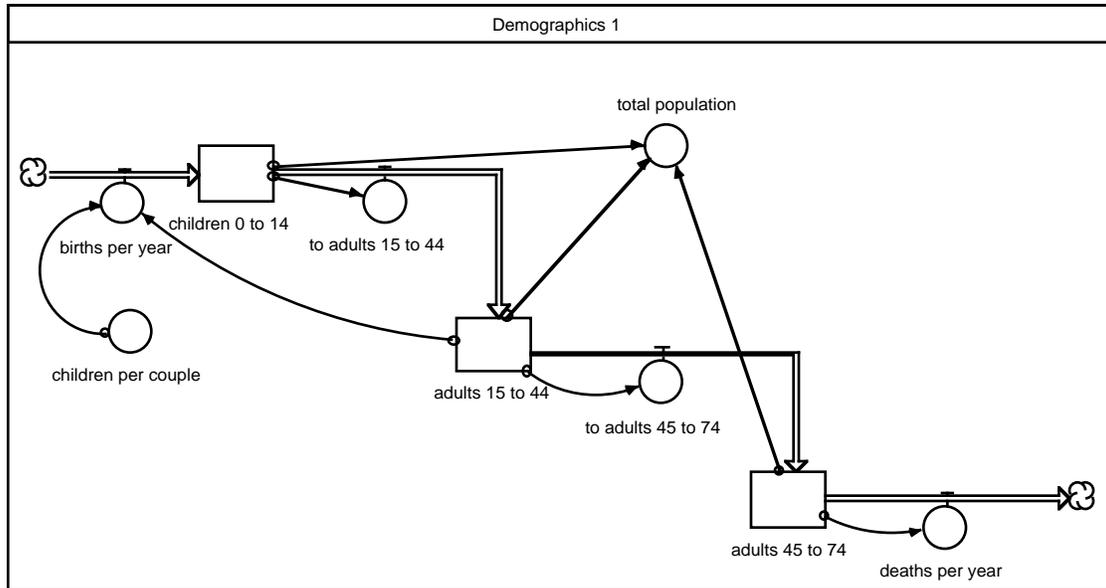
editorial staff: Philipp Portscheller, Landesinstitut für Schule und
Weiterbildung

1995

World population is a topic often discussed both inside the classroom and out. The topic of demographics is here divided into 2 parts.

Demographics 1

1) (This model should be pre-built and handed out to the students.) The following model is a population model. Like all computer models, this model is a simplification of reality. Describe the population model. Which simplifications does the model make? How could you make the model better?



Model 3

MODEL 3 DOCUMENTATION

$$\text{adults}_{15_to_44}(t) = \text{adults}_{15_to_44}(t - dt) + (\text{to_adults}_{15_to_44} - \text{to_adults}_{45_to_74}) * dt$$

$$\text{INIT adults}_{15_to_44} = 300$$

INFLOWS:

$$\text{to_adults}_{15_to_44} = \text{children}_{0_to_14} / 15$$

OUTFLOWS:

$$\text{to_adults}_{45_to_74} = \text{adults}_{15_to_44} / 30$$

$$\text{adults}_{45_to_74}(t) = \text{adults}_{45_to_74}(t - dt) + (\text{to_adults}_{45_to_74} - \text{deaths_per_year}) * dt$$

$$\text{INIT adults}_{45_to_74} = 300$$

INFLOWS:

$$\text{to_adults}_{45_to_74} = \text{adults}_{15_to_44} / 30$$

OUTFLOWS:

$$\text{deaths_per_year} = \text{adults}_{45_to_74} / 30$$

$$\text{children}_{0_to_14}(t) = \text{children}_{0_to_14}(t - dt) + (\text{births_per_year} - \text{to_adults}_{15_to_44}) * dt$$

$$\text{INIT children}_{0_to_14} = 150$$

INFLOWS:

$$\text{births_per_year} = (\text{adults_15_to_44} * \text{children_per_couple}) / 60$$

OUTFLOWS:

$$\text{to_adults_15_to_44} = \text{children_0_to_14} / 15$$

$$\text{children_per_couple} = 6$$

$$\text{total_population} = \text{adults_15_to_44} + \text{adults_45_to_74} + \text{children_0_to_14}$$

2) Click open all the variables on the previous model. Copy down all the values and formulas onto a table.

3) Without simulation, what are the values of the following:

Children 0 to 14 after one year:

Adults 15 to 44 after one year:

Adults 45 to 74 after one year:

Given the following formula for Births per year:

$$= (\text{Adults 15 to 44} * \text{Children per Couple}) / 60$$

What is the significance of the 60?

4) Small Projects Ideas:

You can simulate the model for the next hundred years. You can also change the values of some of the variables. What happens when there are many more Children 0 to 15? What characteristics does the growth pattern have, when the number of children per couple is raised?

Try building a model incorporating family planning. This could be done by limiting the number of children per couple when the population hits a certain value. Share your approach with the class.

5) Insert the following table function in the model. What does it mean? What is the input and the output? What value do the children per couple have at the time $t=45$ years?

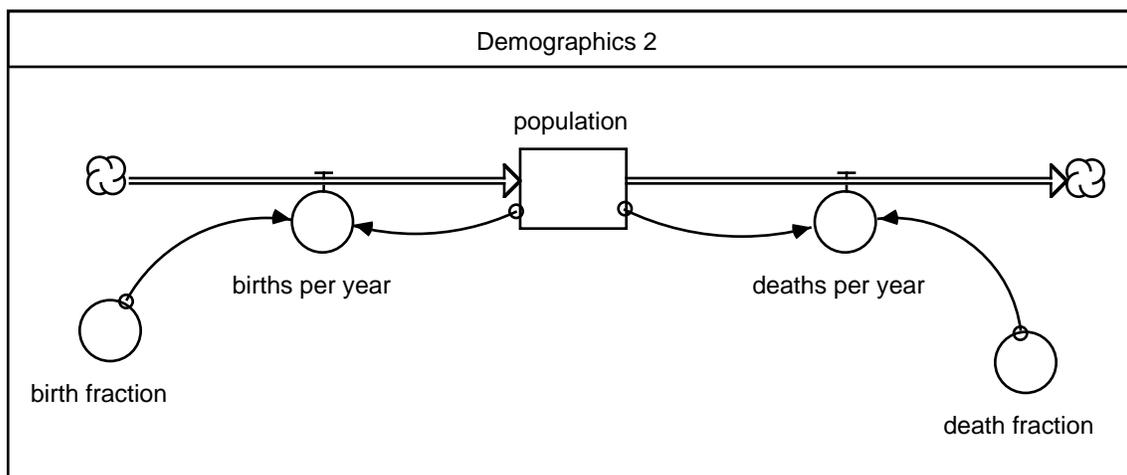
Children per couple = GRAPH (time) (0 , 6) (10, 6) (20, 6) (30, 6) (40, 6) (50, 1.2) (60, 1.2) (70, 1.2) (80, 1.2) (90, 1.2) (100, 1.2)

6) One simplification of the model was that there were no deaths in the 0 - 14 and 15 - 44 age groups. Look up the official statistics and add the structure to the model.

7) (Students should be given data tables containing the population numbers for the values of the stocks from many different countries) Compare the numbers of children per couple, the death rates and other figures for many different countries? Do you see any patterns?

Demographics 2

1) Below is another population model. Describe the model. What simplifications are made here?



Model 4

MODEL 4 DOCUMENTATION

$$\text{population}(t) = \text{population}(t - dt) + (\text{births_per_year} - \text{deaths_per_year}) * dt$$
 INIT population = 100

INFLOWS:

$\text{births_per_year} = \text{population} * \text{birth_fraction}$

OUTFLOWS:

$\text{deaths_per_year} = \text{population} * \text{death_fraction}$

$\text{birth_fraction} = .02$

$\text{death_fraction} = .01$

2) (Students should be given the model pre-built.) Click open all the variables and make a table with all the values and formulas. What do the terms birth fraction and death fraction mean?

3) Without simulation, calculate by hand the value of the population after 1 year. Then check against the computer.

4) Small Projects:

Find all values of the model for the populations of China and Holland.

Using the model, make a forecast of what will happen in the next 5 years.

Add family planning to the model. When a certain population is hit, the birth rate (as opposed to the children per couple in the previous model) must be affected.

4. Lesson Three: Topics in Chemistry

VORABDRUCK CHEMIE

distributor: Landesinstitut für Schule und Weiterbildung
Paradieser Weg 64
59494 Soest
Germany

adapted by: Michael Weingend
editor: Hans-Ulrich Dönhoff
word processing: Dagmar Diemel

1994

There are many experiments that can be done in the lab, as well as modeled using system dynamics. Crystal growth, titration, chromatography and the recycling of metals are perfect examples. A recommended way of implementing system dynamics into the lab is to have the student first do the experiment and record the results. Then the student should build the model on the computer and compare the results. By building the model, the student will get a better understanding of the actual process behind the experiment. The example we will go through here is ion extraction.

Experiment:

25 ml saturated water solution of potassium-iodide ions is placed in a bulb flask.

5 ml of benzene is layered on top. The color of the water should begin to fade as the benzene solution turns violet. Before moving on to the modeling part of the lesson, students should understand what diffusion, phase gradient, ion concentration, equilibrium, and diffusion constants are.

Exercises to be done by the student:

1) Examine the model diagram below. Given the following initial values, fill in the rest of the formulas:

concentration of ions in water = 1 (initial)

concentration of ions in benzene = 0 (initial)

diffusion constant water to benzene = 0.1 (initial)

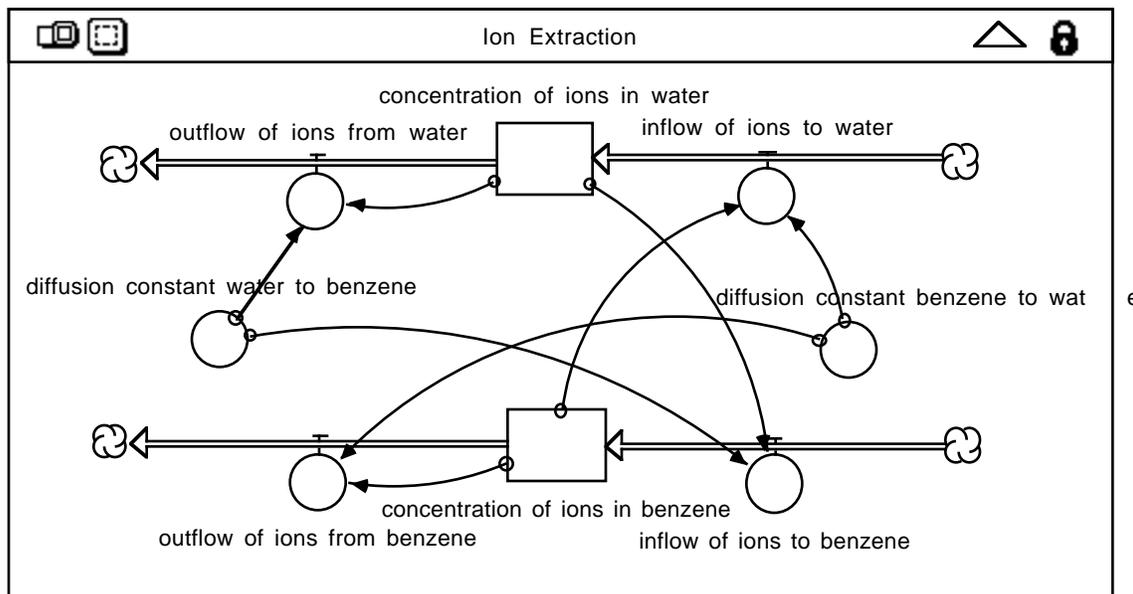
diffusion constant benzene to water = 0.1 (initial)

outflow of ions from water = ?

inflow of ions to water = ?

outflow of ions from benzene = ?

inflow of ions to benzene = ?



Model 5

MODEL 5 DOCUMENTATION

Ion Extraction

$$\text{concentration_of_ions_in_benzene}(t) = \text{concentration_of_ions_in_benzene}(t - dt) + (\text{inflow_of_ions_to_benzene} - \text{outflow_of_ions_from_benzene}) * dt$$

INIT concentration_of_ions_in_benzene = 0

INFLOWS:

inflow_of_ions_to_benzene =

concentration_of_ions_in_water*diffusion_constant_water_to_benzene

OUTFLOWS:

outflow_of_ions_from_benzene =

diffusion_constant_benzene_to_water*concentration_of_ions_in_benzene

concentration_of_ions_in_water(t) = concentration_of_ions_in_water(t - dt)

+ (inflow_of_ions_to_water - outflow_of_ions_from_water) * dt

INIT concentration_of_ions_in_water = 1

INFLOWS:

inflow_of_ions_to_water =

diffusion_constant_benzene_to_water*concentration_of_ions_in_benzene

OUTFLOWS:

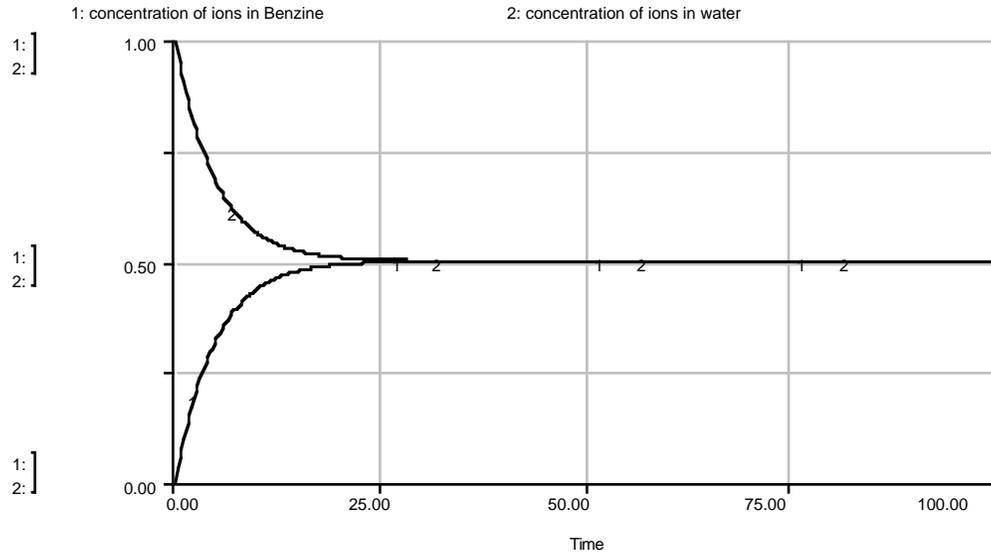
outflow_of_ions_from_water =

diffusion_constant_water_to_benzene*concentration_of_ions_in_water

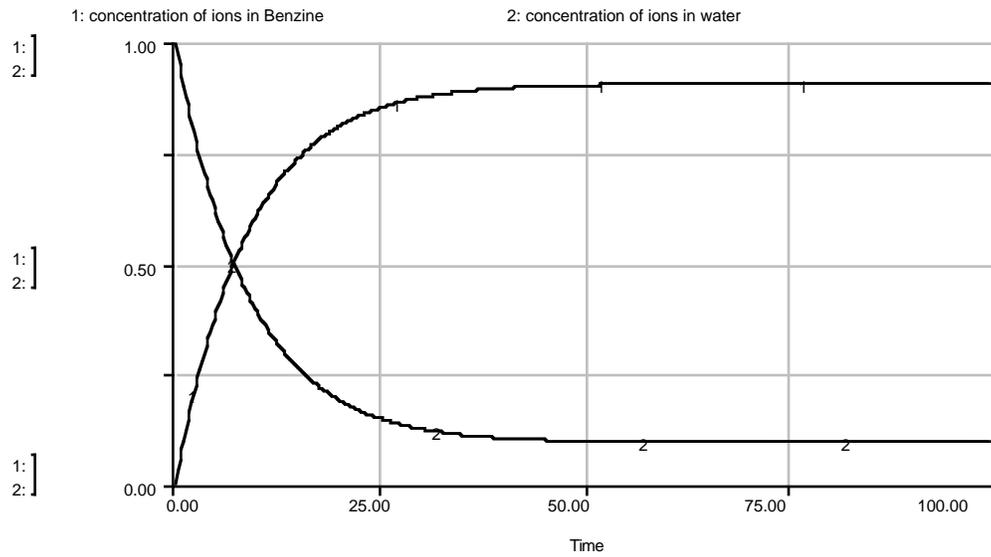
diffusion_constant_benzene_to_water = .01

diffusion_constant_water_to_benzene = .1

2) Below are two graphs. You can simulate them yourself after building the model. Which is a more realistic graph of the system and why? (Teacher's Note: The first graph has both diffusion constants = 0.1. The second graph has diffusion constant of water to benzene = 0.1 and the diffusion constant from benzene to water = 0.01.)



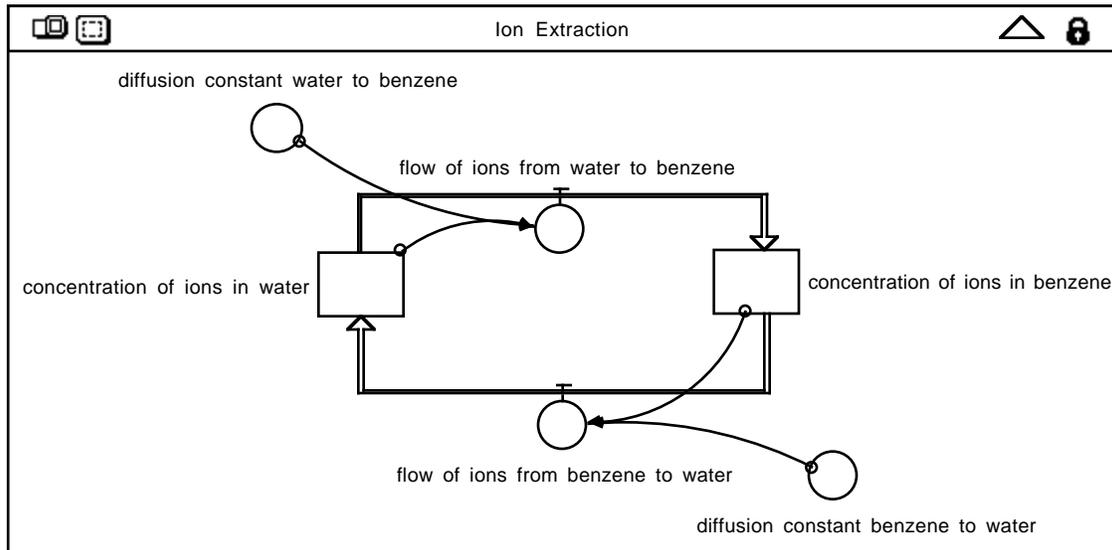
Graph 1



Graph 2

3) Can you build a model of the experiment in a different way? As a class, share your ideas and build the new model? Is this model better? Why?

Sample Answer by translator to question 3:



Sample Answer Documentation

Ion Extraction

$$\begin{aligned} \text{concentration_of_ions_in_benzene}(t) = & \\ \text{concentration_of_ions_in_benzene}(t - dt) + & \\ (\text{flow_of_ions_from_water_to_benzene} - & \\ \text{flow_of_ions_from_benzene_to_water}) * dt & \\ \text{INIT concentration_of_ions_in_benzene} = 0 & \end{aligned}$$

INFLOWS:

$$\begin{aligned} \text{flow_of_ions_from_water_to_benzene} = & \\ \text{concentration_of_ions_in_water} * \text{diffusion_constant_water_to_benzene} & \end{aligned}$$

OUTFLOWS:

$$\begin{aligned} \text{flow_of_ions_from_benzene_to_water} = & \\ \text{concentration_of_ions_in_benzene} * \text{diffusion_constant_benzene_to_water} & \end{aligned}$$

$$\begin{aligned} \text{concentration_of_ions_in_water}(t) = & \text{concentration_of_ions_in_water}(t - dt) \\ + (\text{flow_of_ions_from_benzene_to_water} - & \\ \text{flow_of_ions_from_water_to_benzene}) * dt & \\ \text{INIT concentration_of_ions_in_water} = 1 & \end{aligned}$$

INFLOWS:

flow_of_ions_from_benzene_to_water =
concentration_of_ions_in_benzene*diffusion_constant_benzene_to_water

OUTFLOWS:

flow_of_ions_from_water_to_benzene =
concentration_of_ions_in_water*diffusion_constant_water_to_benzene

diffusion_constant_benzene_to_water = .1

diffusion_constant_water_to_benzene = .1

The reason we can model the system in such a way is that the ions that leave the water go directly into the benzene. Likewise, the ions that leave the benzene go directly into the water. There is an actual, physical transfer of ions. The ions do not change form or combine with other chemicals in either stock. Notice that there are no “clouds” in the system. With an initial concentration of ions in water, no more ions enter or leave the system. The real experiment is a closed system.

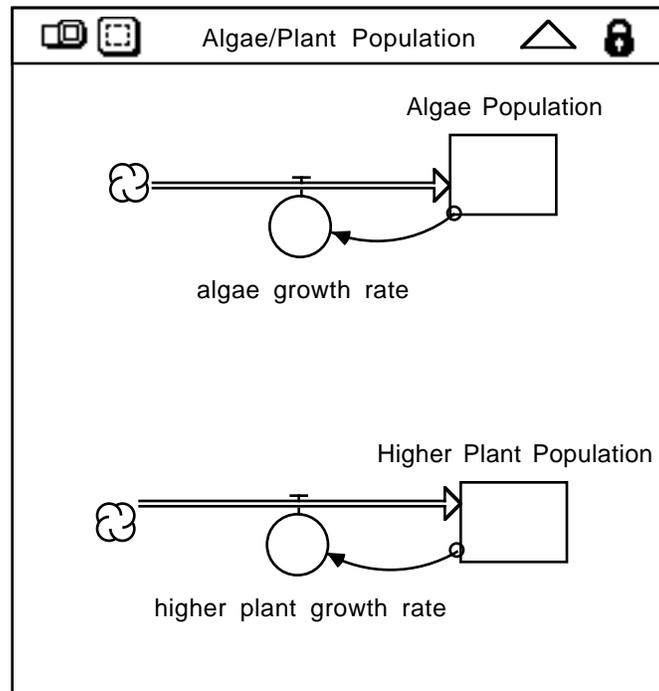
5. Lesson Four: Algae in Abundance

ALGEN IM ÜBERFLUSS

author: Philipp Portscheller

By taking a simple subject such as algae, population models which can exhibit exponential growth and S-shaped growth can be created. System dynamics is a wonderful tool for showing how limiting effects really effect the population. (Graphs were created using runge-kutta-4 and $dt = .125$.)

1) Examine the model, the documentation, the graph, and the table below. The growth characteristics of the higher plants and the algae are identical. Why do the algae outnumber the higher plants, when the initial number of plants = 1000, and algae = 1? Discuss what the growth rate of each is doing.



Model 6

MODEL 6 DOCUMENTATION

Algae/Plant Population

$$\text{Algae_Population}(t) = \text{Algae_Population}(t - dt) + (\text{algae_growth_rate}) * dt$$

INIT Algae_Population = 1

INFLOWS:

algae_growth_rate = Algae_Population

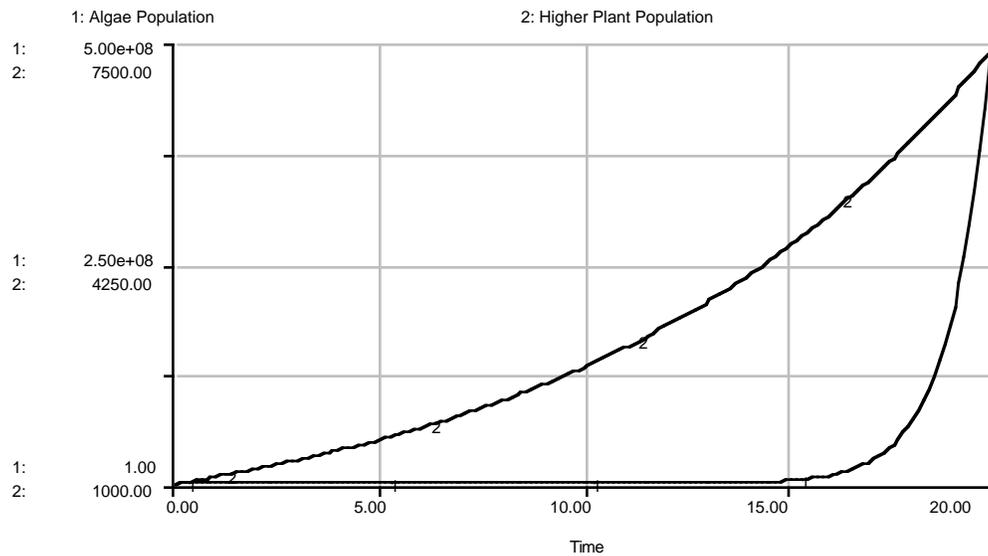
Higher_Plant_Population(t) = Higher_Plant_Population(t - dt) +

(higher_plant_growth_rate) * dt

INIT Higher_Plant_Population = 1000

INFLOWS:

higher_plant_growth_rate = Higher_Plant_Population*0.1

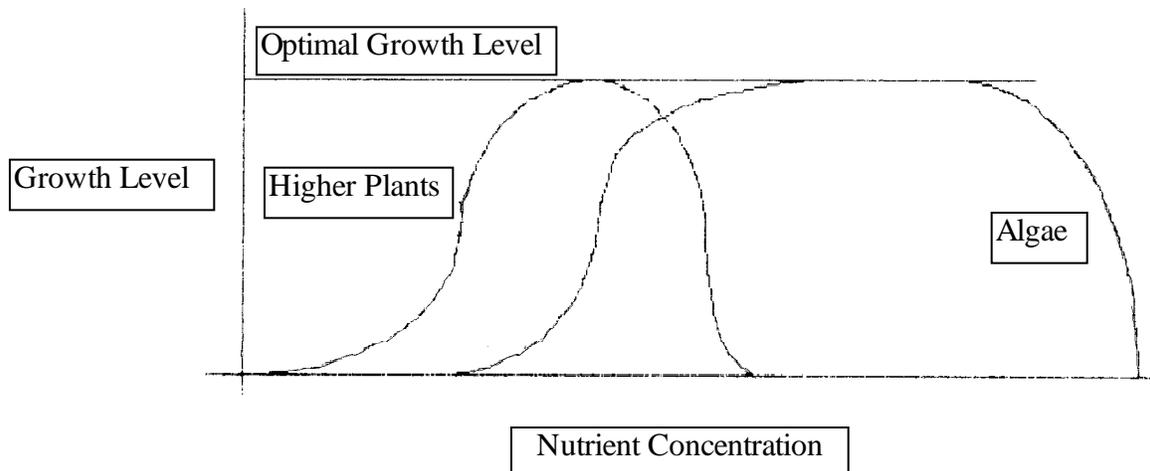


Graph 3

<u>Time</u>	<u>Algae</u>	<u>Higher Plants</u>
	<u>Population</u>	<u>Population</u>
.0	1.00	1,000.00
2.0	7.39	1,221.40
4.0	54.60	1,491.82
6.0	403.42	1,822.12
8.0	2,980.91	2,225.54
10.0	22,026.06	2,718.28
12.0	162,751.21	3,320.12
14.0	1,202,573.41	4,055.20
16.0	8,885,849.84	4,953.03
18.0	65,657,802.16	6,049.65
Final	485,147,404.45	7,389.06

2) Why is the above model simplified and unrealistic? How would you improve it?

3) Explain the following graph in your own words.



Build two models incorporating the relationship you just discovered. Print out graphs of the population for each.

Model 1: (algae) stocks - algae population, nutrient level
 flows - algae growth rate, algae death rate
 graphic converters - algae growth factor: nutrients

Use the following input for the graph: Algae growth factor: nutrients =
 GRAPH(nutrient level) (0,0) (100000, 0) (200000, 0) (300000, 0) (400000, 0.8)
 (500000, 1) (600000, 1) (700000, 1) (800000, 1) (900000, 1) (1000000, 1)...(10000000,
 1)

(Hint: Assume 1% of the algae die each time period. Set the initial level of nutrients = 1000000. What happens to the dead algae?)

Model 2: (plants) stocks - plant population, nutrient level
 flows - plant growth rate, algae death rate
 graphic converters - plant growth factor: nutrients

Use the following input for the graph: Plant growth factor: nutrients =
 GRAPH(nutrient level) (0,0) (100000, 0.115) (200000, 0.275) (300000, 0.42)
 (400000, 0.94) (500000, 1) (600000, 1) (700000, 1) (800000, 1) (900000, 1) (1000000, 1)
 (2000000, 0.9) (2100000, 0.8) (2200000, 0.7) (2300000, 0.6) (2400000, 0.5) (2500000,
 0.3) (2600000, 0.1) (2700000, 0.05) (2800000, 0)

(Hint: Assume 1% of the higher plants die each time period.)

4) Plants and algae live together. Try combining the two models you made in section 3 into one model. Print out a graph with the level of algae, plants, and nutrients.

5) Small Project Ideas:

Think of something else that effects the environment you have modeled. Add it to your model. (example fish)

6. Conclusion

Hopefully this paper has sparked some new ideas of how to incorporate system dynamics modeling into the classroom and will aid in the creation and use of curriculum packets. Even if the students have never been exposed to computer modeling before, much of the software available is easy enough that they can learn while doing.