the Creative Learning EXCHANGE

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LESSONS FOR SYSTEM DYNAMICS MENTORS IN SCHOOLS

by Will Glass-Husain[1]

In the Fall of 1992, I began work as a "System Dynamics Mentor" at the newly opened Catalina Foothills High School (CFHS), part of Catalina Foothills School District (CFSD) located in Tucson, Arizona. In this article, I'll try to summarize my role as well as describe some lessons I've learned while facilitating system dynamics in a public high school.

The Birth of a School

Being part of a new school is an interesting, if somewhat chaotic, experience. New grades are being added at a rate of one each year (ninth grade in the Fall of 1992, tenth grade in the Fall of 1993, etc.). A benefit of this progression is that teachers have a chance to develop one year of curriculum at a time. This is a great opportunity for those teachers interested in system dynamics, for in consultation with me they can cooperatively design lessons and activities utilizing the tools of system dynamics to help implement their curriculum.

In school year 1992-1993, two grants funded the application of "systems thinking" in our district—one for Orange Grove Middle School (OGMS) and one for our high school. These grants funded both organizational learning efforts as well as system dynamics mentoring. I was the mentor at the high school, and Frank Draper split his time between OGMS and the high school. Thus, system dynamics efforts in Catalina Foothills School District have been broadened and substantially reorganized. For the moment I'll restrict my discussion to the mentor positions last year.

Mentor Roles

When I was hired, my job description read (in part) that I should "Develop well-documented STELLA models. Assist staff training in systems thinking and system dynamics." However, the description gave little hint as to how to do so on a day-to-day or month-to-month basis.

Now that I have a year of mentoring experience, I see a mentor as playing several interrelated roles (of course the role of a system dynamics mentor is still evolving, and any description of such a role is necessarily a subjective "snapshot"):

1. Working with teachers on brainstorming, designing, and implementing lessons that use system dynamics tools and activities.

2. Doing programming and model-building as needed to implement these activities.

3. Documenting models and system dynamics activities

4. Training teachers to use and build system dynamic models

5. Serving as a consultant to students as they work on school projects that utilize system dynamics.

6. Encouraging inter-teacher communication on systems issues.

7. Maintaining ties to the system dynamics community.

Note that I don't design curriculum. While I am the expert in regard to system dynamics, each teacher is the expert in regard to their subject area. Ideally, when a course includes a topic that has a strong dynamic component, the teacher will work with me to include system dynamics activities to help teach it. Primarily, I see system dynamics as a method of instruction rather than as a unit of curricula to be taught by itself. Of course this focus on system dynamics as a means rather than an end doesn't preclude teachers from expanding their curriculum to include more dynamic elements after being exposed to system dynamics!

Example Project

In the spring of 1993, the Human Biology teachers taught a unit on anatomy and physiology, structured as follows: At the beginning of the unit, students received a "client" with specific health problems or conditions. Over the next eight weeks, students had

__Lessons__ continued on page 3

UP-DATES...

Ridgewood Public Schools

This has been a year of change at Ridgewood. Tim Lucas has taken on a new challenge as a principal at the Willard Elementary School. He is taking the opportunity to document his path in his first year in his role of principal as a systems thinker. He is putting together appropriate software for each grade level in the school using a combination of SemNet, STELLA and Inspiration. The students are mapping and modeling and using force field diagrams.

His other concentration has been on setting up a series of five formal workshops for parents on systems thinking. We are looking forward to hearing more about what has been going on in Willard as well as at the middle school and high school at the June conference.

System Dynamics in Education Project

The students in Jay Forrester's MIT group are looking into setting up an Internet connection that they would be able to utilize for more efficient dissemination of information about system dynamics in education. If you have any ideas or interest or expertise in that area, contact Jason Fiorillo, eatspam@MIT.edu. He would really enjoy hearing from you

Road Maps V and Road Maps VI are in the works. They are looking forward to the January inter-session as a time to work in a more concentrated fashion than four courses at MIT allow.

Concord-Carlisle

Two years ago, Bill Barnes, a physics teacher in the Concord-Carlisle Regional Schools, attended a week-long workshop for teachers on system dynamics put on by the MIT students in the System Dynamics in Education Project. His enjoyment of the subject and use of STELLA inspired Al Powers, a chemistry teacher, who became fascinated by the subject.

A year and a half ago, the school system made the commitment to give Al Powers a sabbatical to study systems thinking and system dynamics. They have also sent representatives of their middle schools to Tucson for a visit and then for the conference in June. Al followed up with a week-long workshop in August for interested teachers, with the able help of Jeff Potash and John Heinbokel from Trinity College.

This year has been an interesting year for the school system. Al is

Updates continued on page 9

FROM THE EDITOR. . .

As you can see from Will's article in this newsletter, the Catalina Foothills School District has established a structure for mentoring in system dynamics This commitment of resources allows teachers in the classroom to call on help from outside to change and grow their curriculum. It makes good use of the principle that two heads are better than one, a principle often evidenced when we ask students and teachers to work together!

By now all of you should have received the brochure about the Systems Thinking and Dynamic Modelinging conference. There is also a sheet enclosed in this newsletter to inform you about this up-coming conference and post-conference seminar, scheduled for June 27-29, in Concord, MA. If you wish additional brochures just give us a call and we will send them out. We hope to see many of you there.

Lees Stuntz, Editor

GIST TEACHERS

Perhaps the most important section of the article on Glynn Integration of Systems Thinking was mistakenly omitted in the last newsletter—the teachers who worked so hard last year to get the project off the ground and who are continuing to work to keep it a viable part of the Glynn County Schools:

Kathy Alexander (6th grade Language Arts and Math), **Cathy Eaton** (7th grade Science and Social Studies), **Jeff Giddens** (6th grade Social Studies and Language Arts), **Steve Kipp** (7th grade Science), **Jan Mons** (7th and 8th grade Math), **Pam Sederholm** (8th grade Social Studies and Language Arts), **Pat Stanford** (7th grade Math and Science), **Dana Strickland** (6th grade Math and Social Studies), **Sherrill Sumner** (8th grade Science).

These teachers make up a terrific group, and we apologise for the omission in the last issue of *The Exchange.*

NOTICE

If you have an address change, a new e-mail address or any other information about you which has changed—please let us know. Sending in the enclosed questionnaire is a good way of doing so. Let us hear from you.

LESSON IN SYSTEM DYNAMICS MENTORING

continued from page 1

to design a realistic, healthful fitness/ diet/lifestyle plan for the client. All the physiological information they learned during this unit was designed to be needed for this final event. Because the teachers saw a need for system dynamics, they sought me out and invited me to become involved in planning the activities for this unit.

The teachers met with me to study system dynamics a number of times in late winter, both after school and in a day-long workshop. I then worked with a retired Tucson cardiologist doing research on exercise and its effect on the body. By late February, the two of us had created a packet of notes for teachers complete with activity suggestions, causal loop diagrams, and STELLA diagrams. Simultaneously, I programmed a STELLAstack simulation on the effect of exercise on oxygen flow. From the Creative Learning Exchange I also acquired a STELLA model and worksheet covering blood sugar regulation. I worked with all of the teachers on an individual basis to make sure that these materials fit their needs and to train the teachers in their use. Finally, we were ready to start.

In early March, I went through each science class and led a workshop on using causal loops to analyze respiration. I did this to model for the teachers how to use causal loops in the classroom. Some of the teachers followed up in later classes with their own loops or modifications of mine. Since students were required to do two causal loop diagrams as part of their reports, I also met with many students, giving one-on-one advice during my daily "office hours". In addition, I assisted the teachers the first time they ran each activity I had helped design. During STELLA exercises I was in the classroom even more frequently.

I am not so completely involved with every project. Since this was the first science unit to heavily incorporate system dynamics, I needed to work closely with the teachers. It is also important to note that I did not dictate what teachers did in the classroom. Instead, I provided different resources including examples of activities that they could modify to fit their needs. In future projects with these teachers, I hope to take more of a supporting role and less actual activity design.

Lesson 1: The way to get teachers interested in system dynamics:

(A) Drink lots of coffee

(B) Start with teachers' curriculum

Lessons for Mentors

Lesson 1: How to get teachers interested in system dynamics:

(A) Drink lots of coffee

(B) Start with teachers' curriculum

Any new educational innovation must compete for the school's most valuable resource: teacher time. It can be hard to fight the implied catch-22 situation. Often, teachers need to spend time learning about system dynamics and its application to their subject in order to want to allocate that valuable time to learn about system dynamics.

To deal with this, I have two strategies. Number one is to talk about system dynamics all the time. The best place to plant a seed of interest is not in a formal meeting, but random interactions, for example, by the coffee machine (hence lesson 1a). When I have a project going with a teacher, I tell other teachers about it, describe the interactions of kids, even invite people into the classroom to observe. Strategy two is to work with the teacher using his/her own curriculum. Ask, "What would you like to do better?" Look for dynamic elements in that teacher's curriculum. Find examples of reinforcing and balancing loops. Discuss what kinds of uses the teacher might find for system dynamics while dealing with content.

Lesson 2: For release time to be valuable it must be used in a relevant, well-structured manner.

Teachers need time to brainstorm ideas, learn skills, and develop and evaluate activities and lessons. Last year a system was set up whereby every teacher was allotted a daily an equal amount of release time, funded by the grant, whether or not they were using system dynamics. The consequence of this structure was that the release time was not very useful in regard to system dynamics, because the time was swallowed up under the enormous responsibilities of day-to-day teacher life and general curriculum development. This year, the "release" money will primarily pay for substitutes while teachers leave the classroom and do planning specifically oriented towards system dynamics.

Lesson 3: Don't shift the burden to the mentor.

Research shows that skill-specific training (e.g. short-term intense workshops) is often a poor method of school change. Initially, this type of training has strong, positive effects on the teachers and students involved. "But, when the experts leave, teachers discontinued using the practices that had apparently enhanced student performance because they had never really learned them in the first place."[2]

***Lessons** continued on page 4*

LESSONS FOR MENTORS

continued from page 3

Instead of "giving the answers," informal support may be the solution, both of the coffee machine and classroom variety. Teachers often lack feedback about how they are doing in class. Being an expert "sounding board" for ideas and techniques related to system dynamics may ultimately help a teacher more than expert tutoring.

Lesson 4: Beware the "Everything is a system" philosophy.

This concept and its cousin, "Everything is connected to everything," has gotten system dynamicists in this district into some hot water over the past few years. System dynamics is a specific set of tools (behavior over time graphs, causal loops, STELLA models) that can be used as a method of instruction. However, there has been a tendency for teachers or others to extend the name of system dynamics/ thinking to other techniques and ideas that are used in our district. Parents who have disagreed with one or more of these ideas have at times been vocal in denouncing the use of systems thinking. The best policy is always to discuss specifics with regard to system dynamics, rather than dissolve into meaningless over-generalizations.

Lesson 5: Push generic structures and systems archetypes.

One of the more powerful ideas in system dynamics is generic structures: similar patterns of relationships that cause similar patterns of behavior. Teachers often tend to focus on individual systems (i.e. what they are teaching at the moment) and may need some support in teaching students to recognize and use similarities in their learning.

Lesson 6: Research is needed on which classroom structures work most effectively with system dynamics.

System dynamics is still an educational discipline in its infancy; many issues lie unresolved. Classroom structures referred to include: grouping arrangements, type of tasks students are performing, and methods of assessment. The System Dynamics Project is currently funding a part-time researcher to study this question along with other issues over the next few years.

The New, Improved System Dynamics Project

As I mentioned before, recently the system dynamics efforts in our district have been reorganized with a goal of being more specific in intent. Instead of grants for different schools, we now have one grant funding two distinct efforts: the "Organizational Thinking Project" headed by coordinators Mary Scheetz and Tracy Benson, and the "System Dynamics Project" managed by Joan Yates.

The System Dynamics Project is intended to "use the tools of system dynamics in classrooms to continuously develop the ability of students and teachers to understand complex, dynamic situations."[3] Toward this goal, four full-time mentors are funded: one mentor is covering all three elementary schools, one mentor is at each of the two middle schools, and I am still at the high school. Two of the three new mentors are experienced classroom teachers, but all three are new to system dynamics. Consequently, this year these mentors are interns or "experts-in-training."

Conclusion

Whether you are a teacher, an administrator, or simply a "citizen champion," I hope these lessons are useful for you and your school. I welcome any questions/comments about our program or yours!

***Will Glass-Husain's** experience with system dynamics was originally acquired during the time he worked for the System Dynamics in Education Project at MIT under the tutelage of Jay Forrester. The K-12 orientation of the project and a natural bent for teaching helped Will decide to use his considerable talents working at the Waters Grant Project. Any comments or questions should be directed to Will at: Catalina Foothills High School, 4300 E. Sunrise Dr., Tucson, AZ 85718. (602) 577-5090.*

[1] Will Glass-Husain holds a B.S. in Computer Science from Massachusetts Institute of Technology (MIT). While at MIT, he was part of the System Dynamics in Education Project (SDEP) under Professor Emeritus Dr. Jay W. Forrester, founder of the field of system dynamics. Address: William Glass-Husain, Catalina Foothills High School, 4300 E. Sunrise Drive, Tucson, AZ 85718. (602) 577-5090.
[2] "Staff Development and School Change", McLaughlin and March, *Staff Development: New Demands, New Realities, New Perspective,* edited by Ann Lieberman and Lynne Miller, (1979) New York, Teachers College Press, pp. 69-94.
[3] Waters Grant Project 93-94 Proposal, May 21, 1993, revised/amended June 10, 1993.

TRANSLATOR WANTED

We still hope to locate a translator for the book which Jay Forrester has: a copy of a German text for high school physics which uses STELLA. Jay has permission to translate it into English. It would be a great help to find someone who is able to translate the entire book, but even a translation of the text of the models involved would be a boon to teachers. We have a nibble, but if you could help, please contact Nan Lux, MIT, SPED, E-40-294 Building, Cambridge, MA 02139; (617)253-1574

COOLING CUP OF COFFEE II

Dynamic Models for Instruction and Exploration in Chemistry

BY ALBERT L. POWERS

The cooling behavior of a cup of coffee was first introduced as a subject for computer modeling and systems education by Roberts, et al.[1] More recently, Chung[2] used this system as a tool for differentiating and clarifying the behaviors of constant flow and flow influenced by negative feedback. After incorporating much of Chung's work, *Cooling Cup of Coffee II* transforms the model into an investigative tool that guides students through a careful, stepwise analysis of the structure and behavior of a physical system and provides a stimulus for learner–directed study in the laboratory.

When students are asked what will happen to a hot cup of coffee if it sits for an extended time at room temperature, they will normally respond, "It'll get cold." If pushed a bit further, they may state that heat will flow out into the room. Part II (Linear Heat Loss) includes a model and simulation results for a system so described.

If students follow the construction and simulation of this model with an experimental determination of the actual cooling behavior of a real cup of coffee, they will find that their real-world results do not conform to those generated by the simulation. Having exposed the incomplete nature of their model and, therefore, their thinking, they are confronted with a need for a more precise articulation of system structure.

Part III (Nonlinear Heat Loss Due to Decreasing Heat Content) includes a feedback structure that might evolve if the students concentrate on the fact that a decreasing level of heat in the coffee will be accompanied by a decreasing rate of heat loss. This second model generates a behavior that reflects the laboratory data more closely but still possesses a serious flaw. It fails to stabilize at room temperature!

> ". . .step-by-step detail discourages creative thinking and exploration. . .Modifications encourage explorations of the system's dependence upon other perameters. . ."

Finally, analysis and group discussion should eventually lead to the incorporation of the gap between the coffee and room temperatures as a regulator for the outflow of energy from the coffee as shown in Part IV (Nonlinear Heat Loss Regulated by the Temperature Gap). This modification generates cooling behavior that resembles student laboratory observations quite closely.

Part V (A Model for Exploration) contains modifications to the model that are intended to encourage explorations of the system's dependence upon parameters such as coffee mass, specific heat, varying starting temperatures, and even ambient cooling breezes! These activities can be easily designed and conducted by students on the computer and in the laboratory and are implemented best in an open—ended format. In addition to clarifying fundamental concepts, they provide a unique introduction to the mutually supportive roles of theoretical modeling and laboratory investigation.

This paper does not contain detailed, step–by–step lessons because such detail discourages creative thinking and exploration. Study this resource carefully and then use your own professional abilities to generate an approach that is effective for your program and your students. Modifications, such as providing students with pre-constructed models, are easy to accomplish and can make this activity appropriate for a wide range of grade levels, student abilities, and scheduling parameters.

II. LINEAR HEAT LOSS: MODEL STRUCTURE

The heat energy available is included in Figure 1 as the stock because Joules of energy flow into and out of systems rather than degrees Celsius. The coffee temperature is calculated

***Coffee** continued next page*

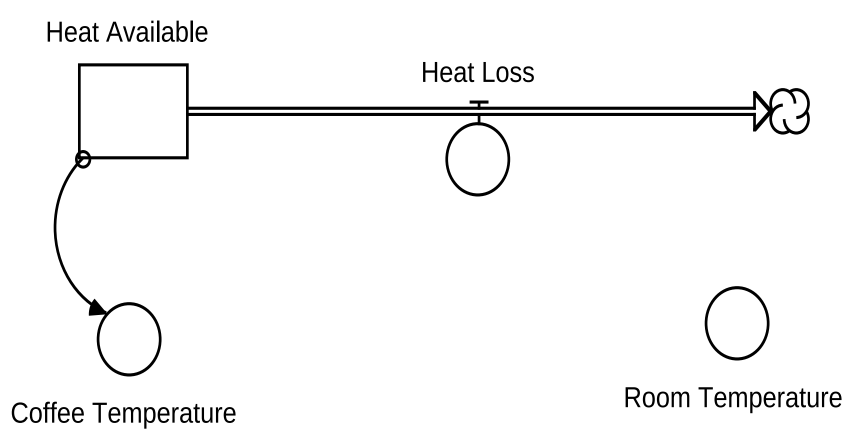


Figure 1. Linear heat flow model

COOLING CUP OF COFFEE II, *continued from page 5*

within the converter. Neither temperature values have impact on the behavior of this system as modeled. The distinction between heat energy available and temperature is important and frequently confuses students. Hopefully, this model structure will help them grasp this concept more fully.

Simulation and Interpretation

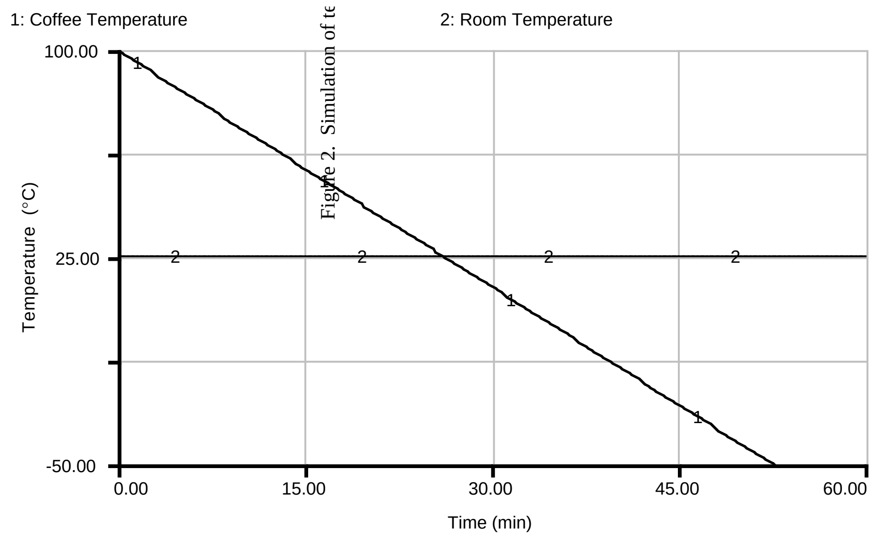
Figure 2 illustrates the linear outflow of energy that results from the absence of a feedback process. Clearly, this pattern will conflict with student laboratory data, not only with respect to its linearity, but also in its extension to values well below room temperature. The presence of both behaviors should compel students to re–evaluate the original model. A possible revision is depicted in Part III.

III. NON-LINEAR HEAT LOSS DUE TO DECREASING HEAT CONTENT: MODEL STRUCTURE

In Figure 3, the connector between Heat Available and Heat Loss establishes the negative feedback loop that would result if heat loss were controlled by the decreasing availability of energy.

Simulation and Interpretation

Figure 4. illustrates the exponential temperature decline that results from the negative feedback connection between heat available and heat loss within the model (Figure 3.) This brings the simulation behavior one step closer to the behavior students should experience in the laboratory. However, the temperature still does not stabilize at the room value. Instead, it continues to drop to values well below room temperature. (The stabilization at -100°C occurs because of the depletion of the energy arbitrarily provided within the stock.) This behavior is corrected in Part IV.



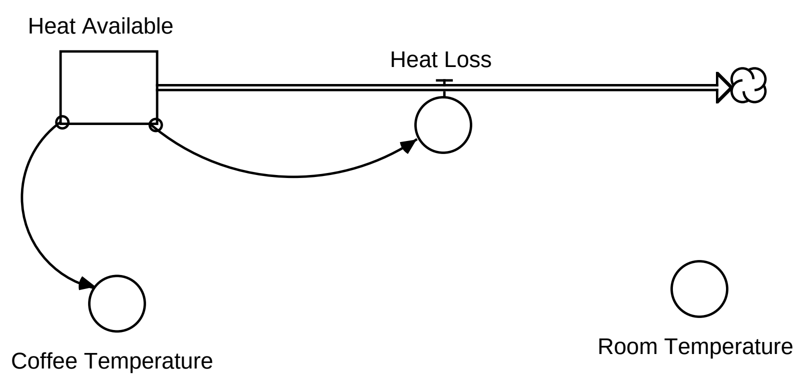
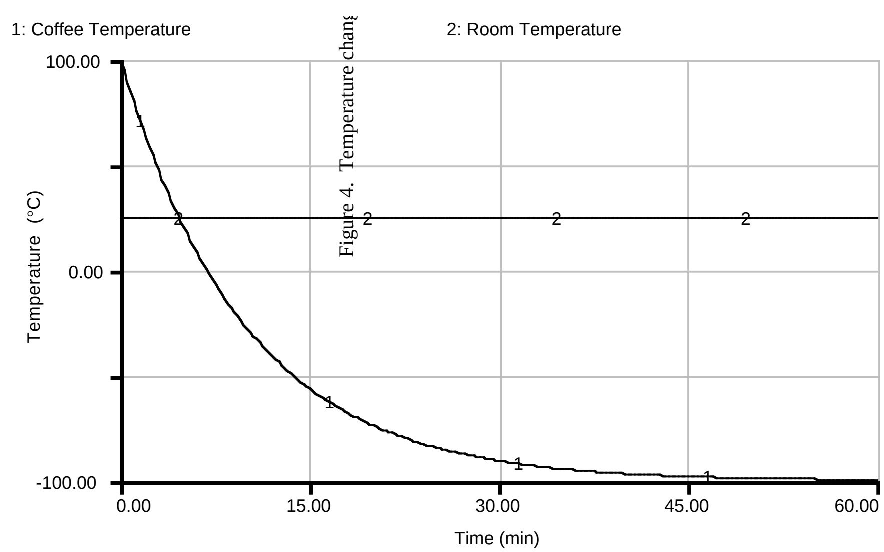


Figure 3. Model for nonlinear heat loss dependent upon heat available.



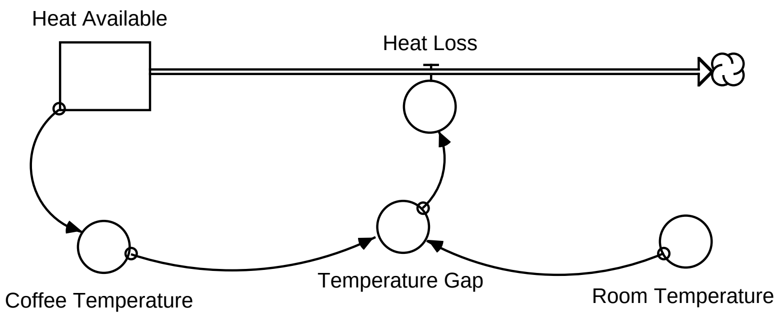


Figure 5. Model for nonlinear heat loss dependent upon the temperature gap.

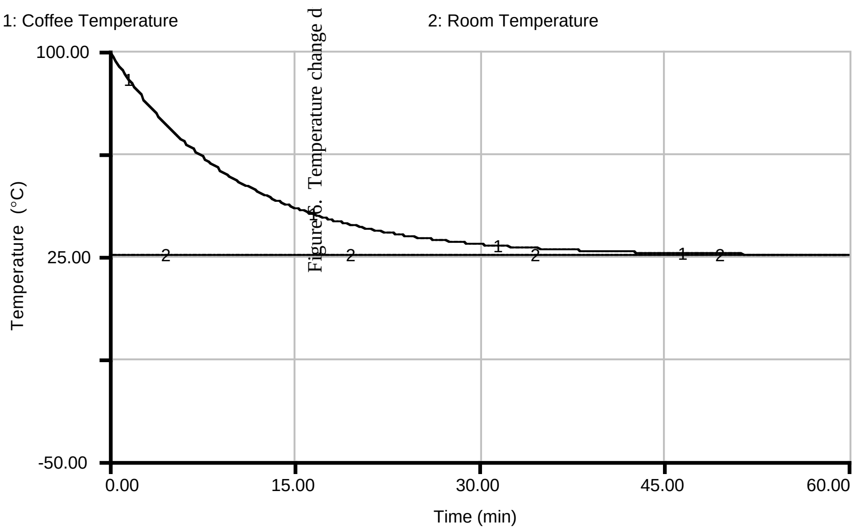


Figure 6. Temperature change d

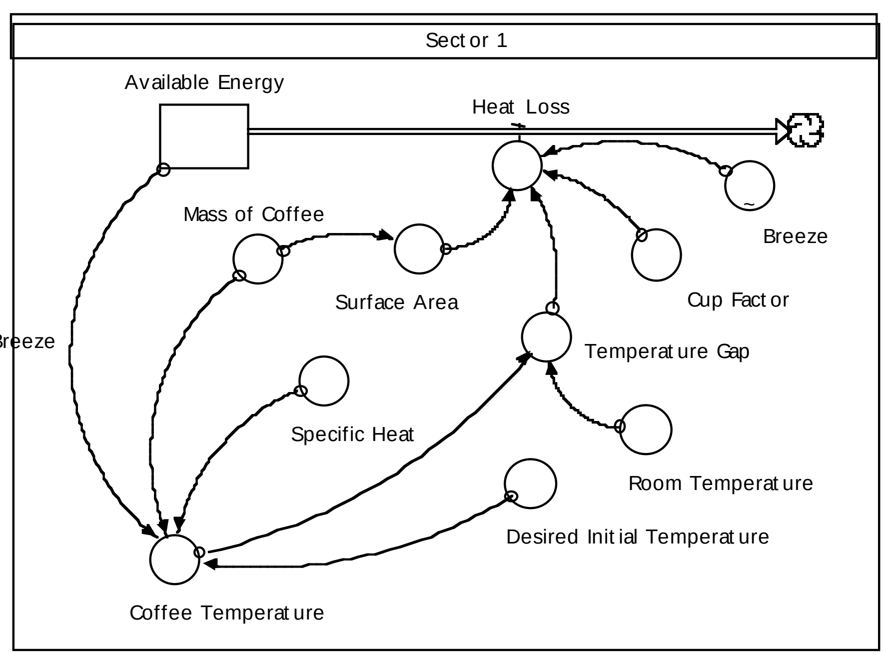


Figure 7. Exploratory model

IV. NON-LINEAR HEAT LOSS REGULATED BY THE TEMPERATURE GAP: MODEL STRUCTURE

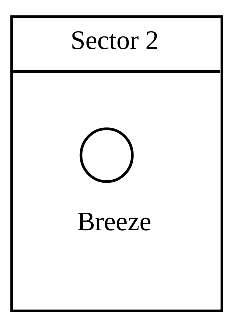
In Figure 5, the feedback loop has been modified to include the controlling influence of the temperature differential existing between coffee and room temperature values. This is the first model of the series that incorporates temperature as anything other than a calculation of convenience.

Simulation and Interpretation

Finally, the simulation results depicted in Figure 6 conform quite well with the cooling behavior students should observe in the laboratory. The exponential temperature decline with stabilization at room temperature should be a consistent feature in all student laboratory work. The rate of change will, however, be dependent upon such factors as the insulating characteristics of their containers, mass of coffee, and air currents. Part V includes some model refinements that will encourage and facilitate student exploration of these influencing factors.

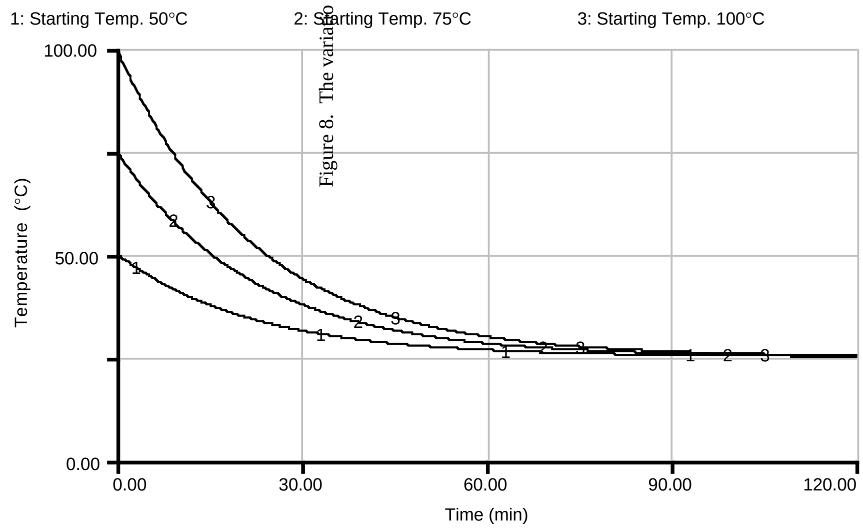
V. A MODEL FOR EXPLORATION: MODEL STRUCTURE

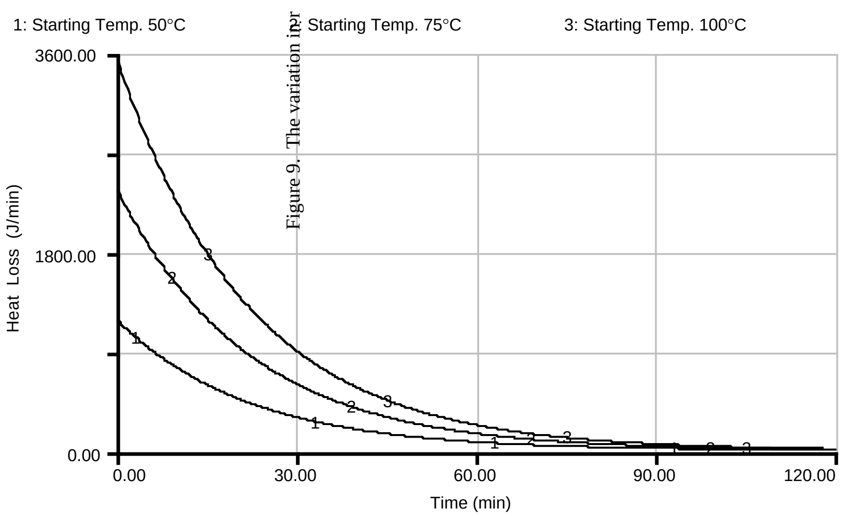
The model depicted in Figure 7 has been created to encourage further exploration of cooling behavior. The mass, specific heat, desired starting temperature, surface area, cup factor, and breeze (activated only if Sector 2 is selected with Sector 1) converters facilitate the varying of these factors singly or in any combination. The sensitivity capability in the STELLA II application provides a convenient method for simulating the effect of changing values.

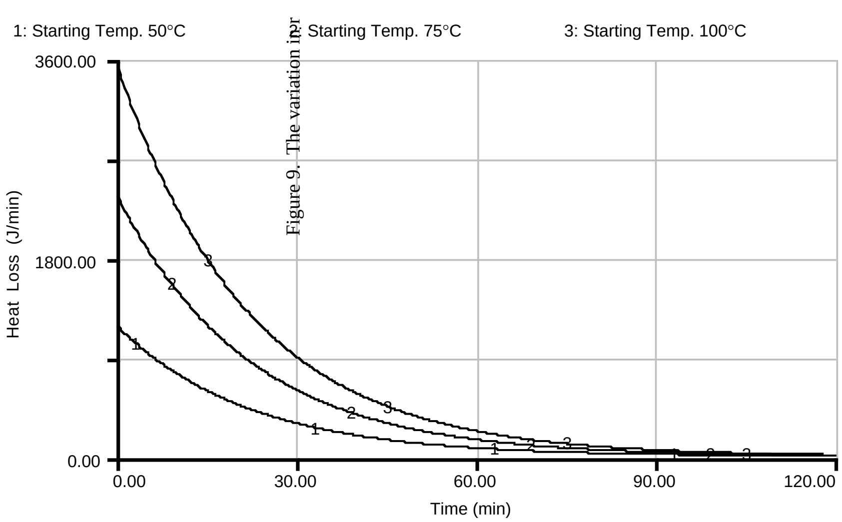


Coffee *continued on next page*

COOLING CUP OF COFFEE II, *continued from last page*







A cycle of prediction, simulation, laboratory study, and reconciliation of differences (including changing the model, if appropriate) will support the development of new insights, inquiry skills, and creative thinking skills.

Simulation and Interpretation

Figures 8 and 9 illustrate the simulated changes in temperature and heat loss commencing with three different starting temperatures (50°C, 75°C, and 100°C). A valuable lesson in energy conservation resides within these graphs. The warmer solution remains warmer through most of the cooling period but possesses a higher heat loss rate than a cooler solution. Clearly, a hot water heater set at 140°F will be cheaper to maintain than one set at 160°F!

Figure 10 illustrates the effect of mass upon the cooling pattern. The modeling of this relationship in particular, requires very careful thought. Clearly, the cooling rate of the coffee depends upon mass and specific heat. But exactly <u>how</u> <u>does</u> it depend upon these parameters? Analyses of laboratory data and alternative model structures have resulted in the constructions used in this paper. The mass and specific heat influence the rate of change in coffee temperature through the coffee temperature converter. The coffee temperature is then used to calculate a temperature gap relative to the room temperature. It is this temperature differential that directly controls the rate of heat loss.

The quantity of coffee in the mug does, however, alter the surface area available for cooling. This influence has been incorporated by calculating the lateral and top surface area that 250 g of coffee would possess in an ordinary mug (see equations). The lateral component of this value is then multiplied by a ratio of the actual mass to the 250 g reference and combined

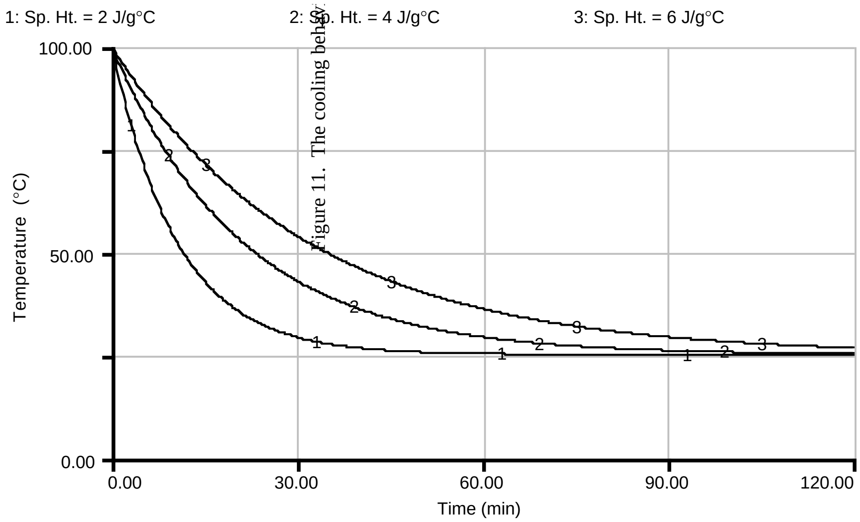


Figure 11. The cooling behav

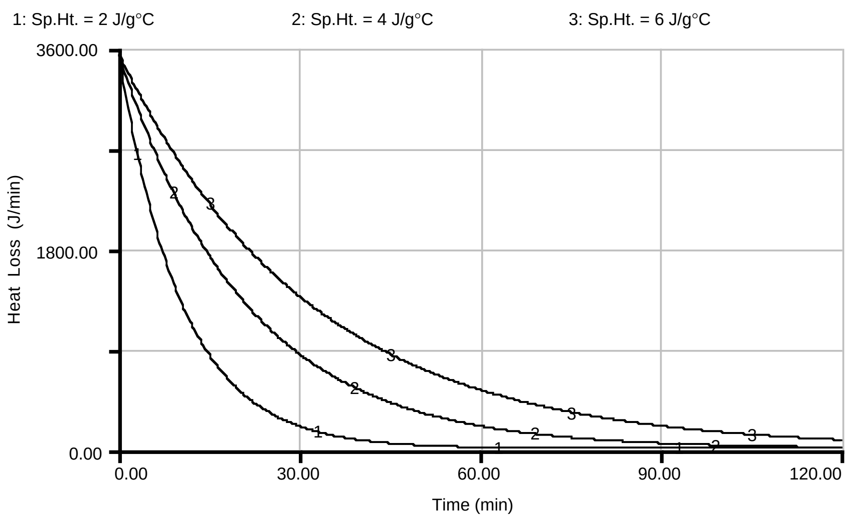


Figure 12. The variation in heat loss rates for solutions of varying specific heats.

with the top surface area to produce an area factor for the final heat loss determination.

The cup factor incorporates a proportionality constant as well as the mass and thermal characteristics of the cup. An interesting project might involve the study of the influence of various container materials and shapes upon cooling rate. Is there an ideal shape for minimizing heat loss? Perhaps you know the answer already. However, students might find the results quite interesting.

The simulation results shown in Figure 11 reflects the impact of specific heat upon cooling behavior. The higher the specific heat value, the more students might find the results quite gradual the temperature change. This results in a higher heat loss rate (Figure 12) throughout the transition period because of the maintenance of a larger temperature gap. The understanding of weather patterns and the identification of effective energy sinks for solar collectors are among the many areas for which this concept has great importance.

Coffee *continued on next page*

UP-DATES: Concord-Carlisle Public Schools, *continued from page 2*

back in the classroom teaching one honors chemistry course, two physics courses, and a science course for the alternative school students. He and Bill now have a total of 13 computers between them and are making good use of them.

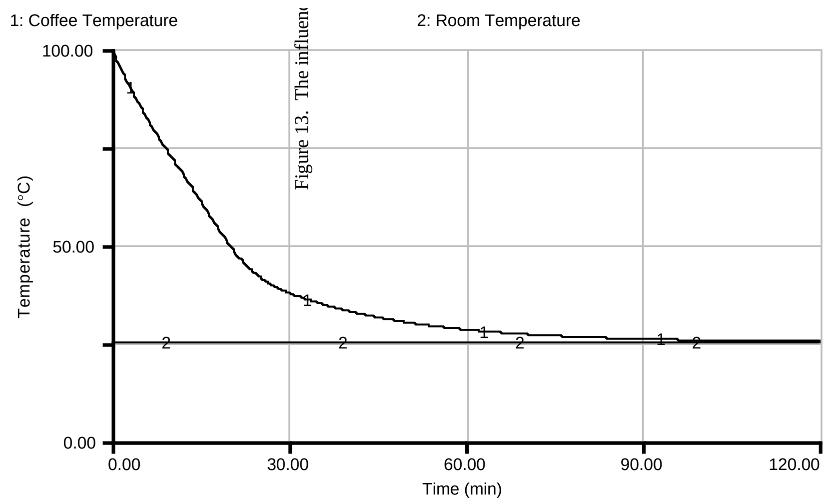
Bill has been using his models on interactions of bodies in space, giving the students insight into orbital paths and gravitational patterns. Al has used his Cooling Cup II (see the article in this issue of the *Exchange*) as well as models on velocity and decomposition of a solid. He has had a student develop an interesting model on energy changes during phase transitions. His latest model, which he has just finished and on which the students are hard at work, is on water vapor and ideal gas dynamics.

The middle school in Concord plans to play Fish Banks, Ltd. with all the eighth graders in their science classes this year. They are exploring system archetypes and their uses in classrooms for this age group.

(ed. note: I miss the pleasure of Al's companionship in learning and exploring this year, but it is thrilling to see what he can do in the classroom—what lucky kids!! It is perfectly obvious, again, what one dynamic, committed teacher can accomplish in a school system with support from the administration or a citizen advocate.)

COOLING CUP OF COFFEE II, *continued from page 9*

The cooling irregularity illustrated in Figures 13 and 14 is often seen in student laboratory work. By selecting Sectors 1 and 2 together to allow the breeze converter to exert its influence—analogous to opening a window—it is possible to simulate the abnormal behavior and to explore its cause. This analysis is much better than ignoring or 'justifying' the deviation as so-called observer error as many students are prone to do!



VI. SUGGESTIONS FOR INSTRUCTION AND EXPLORATION

Formal outcomes of *Cooling Cup of Coffee II* will vary with its audience and mode of implementation. However, general objectives might include (1) the enhancement of critical thinking skills and (2) the development of understanding of the cooling behavior of a liquid and the factors upon which this behavior depends. These can be accomplished by:

- eliciting initial student predictions and explanations for the cooling behavior of a liquid.
- modeling and simulating these behaviors.
- evaluating the simulated behavior by conducting laboratory investigations.
- reconciling simulated behavior with laboratory observations.
- changing the model to reflect and account for observed behavior in the laboratory.
- using the model and simulations as a stimulus for learner–directed inquiry that includes the formulation of hypotheses, laboratory investigation, and reconciliation of the model and observed behaviors.

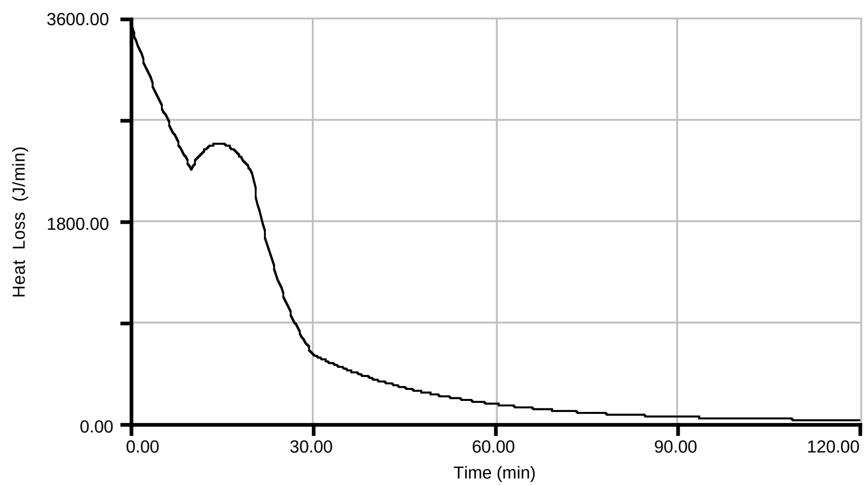


Figure 14. The influence of an ambient breeze upon the rate of heat loss.

Upon the completion of such an instructional sequence, students should be able to:

- explain the difference between heat content and temperature of a substance.
- explain and perform calculations illustrating the dependency of temperature upon heat content, mass, and specific heat.
- explain and model the role of the temperature gap in determining cooling behavior as a negative feedback process.
- identify and explain relevant applications of these concepts.
- demonstrate improved critical thinking skills by modeling and investigating a second system such as cooling behavior through a phase transition.

Specific suggestions for the instructional use and exploration of these models are provided throughout *Cooling Cup of Coffee II.* They are listed below along with a few additional ideas.

- Bring a hot cup of coffee into class and ask students to describe fully their beliefs concerning its behavior over time. This might be best done with students collaborating in small groups. Encourage graphical predictions. Support this activity with both laboratory and modeling experiences.
- Modify the previous activity by bringing in several different liquids (hot chocolate, syrup, rubbing alcohol, etc.) and challenging them to predict, verify, and explain the cooling characteristics of each.
- Have students vary the mass of the liquid in the laboratory and on the computer and compare the behaviors. If differences exist, account for them and modify the model if appropriate.
- Does the specific heat impact the cooling pattern only at the point of the coffee temperature calculation? Change the model to reflect other possibilities and compare simulation outputs with real lab data.
- Experimentally determine the thermal characteristics of cup materials and use these values to refine the model structure.
- Modify the model to illustrate the effect of evaporation upon the cooling pattern. Conduct laboratory investigations to validate the new structure.
- Identify optimum dimensions for minimal heat loss from specific fluid volumes and compare these results with the dimensions of home hot water heaters, thermos bottles, etc.
- Have students modify the model to simulate the warming of cool solutions to room temperature.

The Cooling *Cup of Coffee II* should be viewed as a story with no end. Contributions to its further development are encouraged and will be appreciated and enjoyed. They may be sent to the author directly or through the Creative Learning Exchange.

Dynamic Models for Instruction and Exploration in Chemistry is a collection of interactive computer models intended for use in introductory chemistry programs. Each model clarifies fundamental chemical concepts and encourages their exploration by simulating the dynamic behavior of carefully selected systems.

These models have been developed using STELLA II v. 2.2.2 software and contain:

- structural diagrams that identify essential system components and their interrelationships.
- equations needed to define the quantitative behavior of each component and its impact on the entire system.
- animated, graphical, and tabular representations of system behavior with interpretive material.
- suggestions for instruction and for enrichment activities.

They are unique in their ability to enhance student understanding and appreciation of chemical systems. Features which contribute to this uniqueness include:

- spatial relationships of system components that will have appeal for students who find it difficult to contemplate systems that they cannot observe directly.
- quantitative relationships that are clearly defined and are accompanied by documentation intended to facilitate fundamental understanding and to encourage manipulation of variables.
- dynamic simulations of the behavior of all parameters that may be selected individually or in combination and viewed graphically or in tabular format as desired by the learner.

The intuitive qualities of STELLA II are truly empowering and provide a platform for learner–directed

Coffee *continued on next page*

WANTED: RESOURCE BIBLIOGRAPHIES

Several people have asked us for a list of resources—interesting materials as well as books and articles about systems thinking, system dynamics and learner-centered learning. We would like to put out such a list with references to convenient places for obtaining the materials.

If you have materials you have found helpful: books, software, tapes or other resources for teachers and administrators as well as for children, we would love to have them on our master list. A compilation of this sort could be very helpful to others. We would like to have it done in time to hand it out at the conference. Please help us out. Thank you in advance!

Lees Stuntz

COOLING CUP OF COFFEE II

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learning that not only effectively generates insight and mastery, but is also grand fun! Although you may choose to have your students simply view and interpret the behavior generated by these models, you will likely encounter an irresistible urge to modify and explore the models further. This activity should always be encouraged. Of course, backup the models and graphs first!

Computer simulations make it no longer necessary to rely solely upon discrete, initial and final state observations and calculations to generate understanding. However, they <u>must never be implemented as a substitute for direct observations of chemical interactions in the laboratory</u>. Such experiences offer excitement, relevance, insights, and skills unattainable by other means.

Use these models as part of a balanced program to provide a dynamic introduction to chemistry that promises to reach many who might otherwise find it too abstract, elusive and, therefore perhaps, uninteresting. Then share your experiences and those of your students with others by communicating them to the author directly or through the Creative Learning Exchange.

1 Roberts, N., Anderson, D., Deal, R., Garet, M., Shaffer, W., Introduction to Computer Simulations, Addison Wesley, Reading, MA 1983.

2 Chung, C., A Cooling Cup of Coffee: An Introduction to Constant Outflow and Negative Feedback, MIT System Dynamics in Education Project, D-4292-1, MIT, Cambridge, MA 1993.

3 High Performance Systems, Inc., 45 Lyme Road, Hanover, NH 03755

4 Creative Learning Exchange, 1 Keefe Rd., Acton, MA 01720

***Al Powers** is a science teacher at Concord-Carlisle High School, Concord Massachusetts. He took a sabbatical last year to become familiar with system dynamics and systems thinking. This paper and the others in his series <u>Dynamic Models for Instruction and Exploration in Chemistry</u> are a significant contribution to the use of dynamic modeling in the classroom. All of them are available from the Creative Learning Exchange.*

INTERESTED IN INVESTING?

All of us are interested in promoting the use of systems education in our schools. A number of you have asked if there is a charge for the services of the Creative Learning Exchange, or what you can send to help defray the costs of printing and mailing to you.

The Creative Learning Exchange will continue to send out materials free of charge to all those on the mailing list, regardless of their desire to invest at this time. However, if you would like to invest in our effort here at the Creative Learning Exchange, your contribution would be appreciated. You may donate any amount you wish; perhaps $25 is a reasonable amount for a year. All contributions are tax-deductible.

I am sending ________ to *Trust in Diversity* to help invest in the future of systems education .

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