the Creative Learning EXCHANGE

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A COOLING CUP OF COFFEE

by Celeste V. Chung[1]

Produced for the MIT System Dynamics in Education Project under the Supervision of Dr. Jay W. Forrester

One can visualize and comprehend a one-level constant outflow system, but in reality, few systems like these exist. *A Cooling Cup of Coffee: An Introduction to Constant Outflow and Negative Feedback* illustrates that a cup of hot coffee does not cool at a constant rate of outflow. A cooling cup of coffee system contains negative feedback and tries to reach an equilibrium. The coffee cooling rate is dependent on both the coffee temperature and the room temperature. The difference in temperatures causes the heat from the coffee to flow into the atmosphere, thus, cooling the coffee. The following STELLA[2] models and simulations show that a one-level constant outflow system is not a correct representation of reality, while the revised system containing negative feedback is more realistic.

Introduction

Imagine a hot cup of coffee sitting on a kitchen table. After waiting a few minutes, it cools enough for one to drink it. However, many probably cannot explain for certain how or why cooling occurs. Why does the coffee cool? Does it cool constantly, a little bit each minute, or does the temperature follow an asymptotic decreasing pattern?

A Cooling Cup of Coffee: An Introduction to Constant Outflow and Negative Feedback explains what really happens to this hot cup of coffee. This coffee example introduces the ideas of constant rates, negative feedback, and stabilizing behavior to facilitate an understanding of some of the fundamental concepts of system dynamics.

Misconceptions About Constant Rates

Let's examine what happens to the cup of hot coffee while we wait for it to cool. Some people will automatically answer, "Well, the coffee temperature cools by a few degrees each minute and then you drink it." This answer is expressed in Figure #1. People are aware that the coffee is very hot, and that the coffee temperature is much higher than the room temperature. This causes the coffee to cool a little each minute until it reaches a drinkable temperature.

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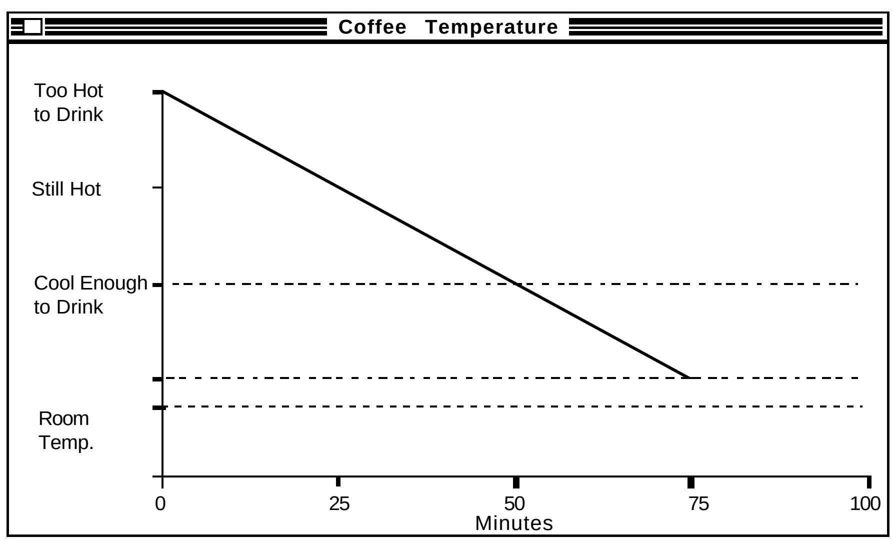

Figure#1 In this graph, a cup of coffee starts off at a very high temperature and cools for 7.5 minutes. At that point, the coffee is very cool and is consumed. This graph of temperature is one way of thinking about the coffee system. A better way, however, is to model in terms of heat.

UP-DATES...

<u>CC-STADUS- Cross Curricular Systems Thinking and Dynamics Using STELLA</u>

This project is recently funded by the NSF. Special impetus for this project was created by Diana Fisher, a math teacher in the Portland Oregon schools. She is ably joined by Ron Zaraza, a physics teacher, Dr. Andrew Jones and Steve Carlson in the initiation of this ambitious project. One of the major goals is to train over three years more than100 math, science and social studies teachers to use computer modeling techniques. A more complete description will be forthcoming in later newsletters.

<u>System Dynamics in Education Project</u>

Road Maps IV is finished after a summer's worth of diligent work by the students in the SPED at MIT under the distinguished and able supervision of Jay Forrester and Nan Lux. Road Maps IV is a dynamic and interesting packet. It incorporates the building of a model for the Fish Banks game as well as a look at the Epidemics game. It, as well as RM I-III, is available through the Creative Learning Exchange. If any of you have ideas about helpful projects for these capable students which key into their talents, please let Nan know. They are always interested in feedback about their materials and suggestions for future work. Nan Lux, MIT, SPED, E-40-294 Building, Cambridge, MA 02139; (617)253-1574

<u>June 1993Networking Conference in Tucson</u>

The second Tucson conference had an emphasis on networking both intra-school groups, with school districts to bring along as many people as possible, and between school districts, with a wide dissemination of information about what people are doing throughout the country.

The three day conference stimulated many interesting conversations and the information exchange was incredible. The participants left with a sense of energy, camaraderie and purpose, inspired by such speakers as Donnella Meadows and Stephen Glen.

The Waters Grant Project, and especially Mary Ann Baridon, are to be thanked and commended for the incredible amount of time and love which went into both years of the conferences.

FROM THE EDITOR. . .

This edition of the <u>Exchange</u> has another description of how one school system is introducing systems education. It is yet again a different model from the ones which we have previously featured: Ridgewood, New Jersey and Catalina Foothills in Tucson, Arizona. There are numerous other ways that school systems are approaching the introduction. Can you send me a story? How is it different in your school?

Again, please fill out the questionnaire if you have not done so. We would like to continue sending you newsletters and information, but only if you wish to receive them. I am still looking for feedback. What are you doing? What works and what doesn't? I would love to hear from you.

Have an exciting and interesting school year.

Lees Stuntz, Editor

TUCSON CONFERENCE MOVES EAST

For two years the Waters Grant Project in Tucson has graciously hosted a conference where all of us interested in systems education could learn, talk and become inspired. After all their hard work, they asked at the Networking Conference if there were others willing to take on the work of a conference. A group of us from the East Coast thought there was enough manpower, enthusiasm and energy to try to hold it here.

Although much is still to be formulated, the date and place are now settled: The conference will be held at ***Concord Academy****, in* ***Concord, Massachusetts****, from* ***June 27th through 29th, 1994****.*

Concord Academy is located right in the center of historic Concord. The surrounding area is chock full of interest for everyone, as well as having appealing accessibility to Boston. One reason for going into a school setting is that the rooms available come close to the cost of those in Tucson or other inexpensive portions of the country. We will keep you all posted of plans as we formulate them.

Anyone interested in helping with the conference in any capacity can get in touch with us here at the Creative Learning Exchange, 1 Keefe Road, Acton, MA 01720; (508) 287-0070; fax: (508) 287-0080.

GLYNN INTEGRATION OF SYSTEMS THINKING (GIST)

*Editor's Note: This article is a compilation of descriptions of the project sent by the members of **GIST** and their administrative supervisor and advocate- Pam Lewis, Assistant Superintendent for Instruction*

GIST began in the Spring of 1992. The project participants included the Glynn County School System, Glynn County, Georgia; Georgia-Pacific, Inc.(GP), a pulp and paper company; and High Performance Systems, Inc.(HPS), a computer software company. The goals of the project are to:

- Build Systems Thinking skills among 1st through 12th graders
- Increase the capability for using these skills to accelerate learning
- Increase the capability of Georgia Pacific employees to use Systems Thinking skills in their jobs
- Create a capability within the community for applying Systems Thinking to the issues affecting the Glynn County populace.

Currently, the Glynn County School System consists of two high schools, three middle schools, and eight elementary schools that service a total of approximately 10,500 students. It has a diverse population, ranging from those who live on resort islands to those who live in government projects. The outlying areas of the county are rural. With this kind of diversity, the teachers are faced with a challenging array of students every single day.

Glynn County Schools is an enthusiastic school system that strives to improve the quality of the education for students. The school system's efforts to decrease student under-achievement have been extensive and the teachers have been exposed to many different programs and projects. From the outset, there has been concern that **GIST** not become just one more in a series of projects. The goal of **GIST** is to involve the entire district in Systems Thinking and remain viable for many years.

In the first year, **GIST** involved ten teachers from the three middle schools. Teachers had ten weeks of release time during the 1992-93 school year to create learning environments in the classroom. These core teachers created three interdisciplinary, systems thinking-based learning environments (LEs) for use in middle schools. During the 1993-94 school year, the teachers will begin using these learning environments in the classroom.

During the summer of 1992 workshops were put on by High Performance Systems for interested teachers in the Glynn County system. The ten core teachers then took another, more intensive, workshop. Another innovative feature of the project was the inclusion of a process steward from outside the district . She was familiar with the software, although she fielded any questions to the experts at HPS, who were involved with the project throughout the year. The Steward's job was to make the project work, to help the teachers focus, to give them support, and to help resolve personnel issues which arose during the year. The teachers felt she was a big help and a major reason why the project was successful during the first, learning phase, year.

Goals and Purpose

The goal of the project is to help students recognize their individual skills and abilities so that they may reach their full potential as responsible citizens, problem solvers, and clear communicators.

Traditionally education has concentrated on building students' skills and abilities in individual subjects. This has enhanced their knowledge in specific subject areas and has allowed some students to excel in specific disciplines. We also need to give students the tools necessary to visualize, understand, and communicate how these subjects relate to each other in order for them to become effective problem solvers.

Many students lack motivation for learning academic skills. If they can extend the effort to master any skill they want to learn (sports and hobbies), then educators must create an environment which gives them the same reason to learn an academic skill they think is too difficult or has little meaning for them.

Systems Thinking and STELLA II give us a was to achieve both of these purposes. Systems Thinking gives students the language to communicate the relationships between subjects. STELLA II is the tool which allows teachers to create environments which give students a reason to learn skills in which they might previously have lacked an interest.

Systems Thinking helps students address the increasingly interdependent issues with which people must cope in their personal lives, their jobs, and in their communities. The technology, STELLA II, allows for the compression of space and times so that people can "experience" the full consequences of their decisions over distance and time.

Learning Environment Development

The project plan includes developing a critical mass of materials to be used for instruction. These Learning Environments include a combination of models and curricula.

1992-1993- The following Learning Environments were created. They will be field tested during the 1993-1994 school year. After refinement they will be ready for use in Glynn County and marketing elsewhere.

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GIST *continued from previous page*

- **Eat or Die Island**- A four-week interdisciplinary unit.
- **Predator and Prey** -A one-week interdisciplinary unit.
- **Financial Dreams or Budget Nightmares** - A four-week interdisciplinary unit.
- **A Matter of Balance** - A four-week interdisciplinary unit.
- **Slope** - A one-day Algebra lesson.
- **Fever** - A one-day Science lesson.,
- **Body temperature Maintenance** - A one-day Science lesson.
- **High Wire Balance Act** - A one-day Science lesson.
- **Immigration**- A one-week Social Studies unit.
- **Ozone Layer** - A one-day Science model.
- **Wiz Kid Mission** - A Math problem-solving game.
- **Perimeter, Area and Volume** - A one-day Math unit.
- **Part to whole** - A one-day Social Studies lesson.
- **Landfill**- A one-week Science and Social Studies unit.

1993-1994 -Plan for creating Learning Environments. The program emphasis for this year is to field test existing LEs and develop and teach courses for other teachers in the county. Because of these demands on time and limited financial support, no major interdisciplinary LEs will be created this year. The concentration will be on creating single discipline LEs. Listed below are the LE titles and planned release time for teachers for development and writing.

- **Health and Weakness** - two weeks, two teachers.
- **Salt Marsh** (its use and protection) - two weeks, two teachers.
- **Communication** - two weeks, two teachers.
- **Acceleration of Change** (revolution) - two weeks, two teachers.
- **Graphs and Relationships** - one week, two teachers.
- **Hurricane** - two weeks, two teachers.
- **Plot and Character Development** - two weeks, two teachers.

Staff Development

From the very beginning in this project there has been an acknowledgment that it is critical to train teachers and give them the resources, including time, for them to learn. To the extent that it has been possible, **GIST** has accomplished just that. Three teachers from **GIST** attended the Networking Conference this summer in Tucson and later in the summer three went to an HPS workshop at HPS headquarters in New Hampshire. One of the major goals for this year at **GIST** is the dissemination of the knowledge the core group gained last year out to the other staff in the Glynn County Schools.

They are offering three courses for the staff this year:

- **Introduction to Systems Thinking**- 5 sessions. In this introductory course, participants will investigate the principles and tools of systems thinking, including a definition of a system, how feedback loops work in systems, how our mental models of systems influence our behavior, and how systems can be manipulated. Participants will develop maps of systems, an introductory activity for the modeling skills to be taught in the second systems thinking course.
- **Simulating Systems -** 5 sessions. Participants will be introduced to stocks, flows, converters and connectors and how they are used to represent elements and relationships of systems. The modeling will create simulations of systems and provide a tool for challenging our mental models of these systems.
- **Developing Systems Curricula-** A summer course- Participants will develop their own curriculum materials using the principles and tools of systems thinking that they have learned in the previous courses. They may work individually or within teams to develop material. These materials may be content specific or interdisciplinary and may cover whatever topics the participants wish.

As the project enters its second year, there is excitement and enthusiasm for what has gone on in the past year and what is to come. As with any project of this sort, funding has been and will be an issue. Georgia Pacific has provided most of the funding for the first two years of the project. The goal is for **GIST** to become self-supporting as the program expands. As the program reaches beyond the middle schools, the need to broaden the base of financial support becomes crucial for the survival of the project.

GIST has many elements to help it meet its goal of being a project which makes a difference in Glynn County Schools over a multi-year period. It has strong administrative support, a core of committed and enthusiastic teachers, and support from main industry in the community which has a vested interest in high-quality education.

*The CLE has more detailed descriptions of the three interdisciplinary units created by **GIST**. For more information about the project itself, contact Pam Lewis, Assistant Superintendent of Instruction, Instructional Services, Glynn County Schools, 2400 Reynolds Street, Brunswick, GA 31520, (912) 267-4220.*

DO YOU KNOW BOTH GERMAN AND PHYSICS?

Jay Forrester has a copy of a German text for high school physics which uses STELLA, and 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. If you could help, please contact Nan Lux, MIT, SPED, E-40-294 Building, Cambridge, MA 02139; (617)253-1574

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Although many tend to think of the "hotness" of coffee in terms of temperature as in the graph above, the correct way to measure "hotness" is actually in terms of heat. Temperature is a *measure* of heat, and also the size and physical nature of the body containing the heat. However, the coffee loses heat, not temperature, because heat can flow from a body of high temperature to a body of low temperature.[3] Temperature can not physically flow. Figure #2 represents the model of our cooling cup of coffee in terms of heat.

What would happen to a cup of coffee, cooling at a constant rate, if you left it on the table and forgot about it for a few hours? Figure #3 represents this constant rate cooling cup of coffee system.

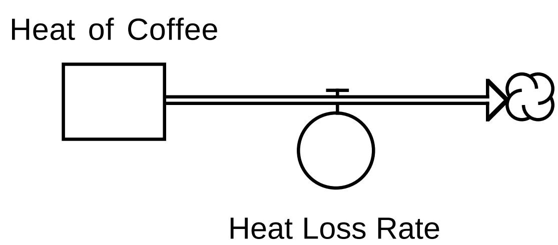

Figure #2 This STELLA II model represents a cooling cup of coffee that loses a constant amount of heat each minute. The coffee loses heat and not temperature because heat can physically flow while temperature cannot. Temperature depends on the amount of heat and the nature of the body containing the heat.

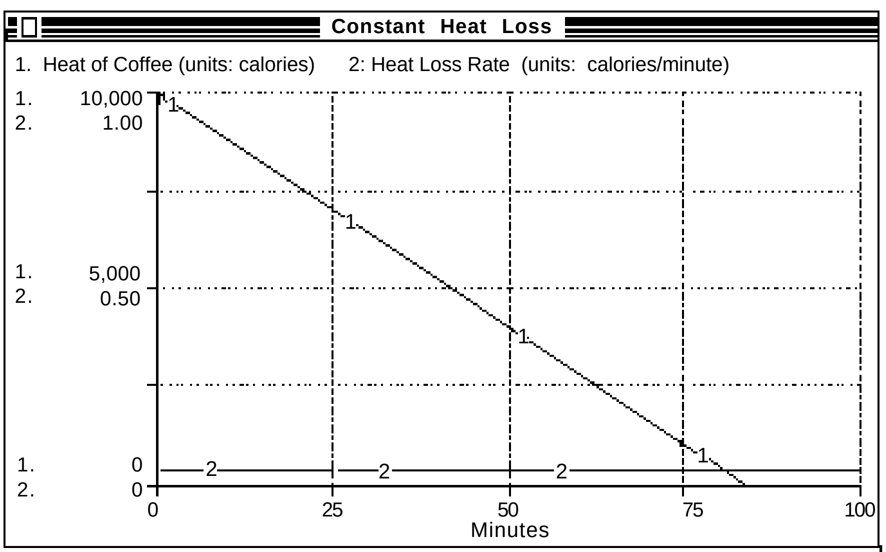

Figure #3 In this graph, the number one line represents the amount of heat in the coffee. The coffee loses a constant number of calories a minute. The heat outflow is a constant rate represented by the number two line.

Because the oversimplified model shown above contains a constant **Heat Loss Rate**, without anything to discontinue the cooling, the **Heat of the Coffee** will continue to lose heat even after it has reached room temperature. See Figure #3. In this model, there is no connector between **Heat of Coffee** and **Heat Loss Rate**. Therefore, when the heat in the coffee is equal to the heat at room temperature, there is nothing in the model to tell the **Heat Loss Rate** to stop. It is intuitive that a cooling cup of coffee does reach an equilibrium at room temperature. Thus, the previous model is lacking something. The difference in the coffee and room temperatures must affect the rate, and these factors are missing from the model. The model shown in Figure #2 may seem correct, but it is not.

We know that the previous model is not complete, not only because it does not make sense intuitively, but also because it defies laws of thermodynamics. If we allow the model to continue running, it would continue to remove heat from the coffee even after it reaches the freezing point of water. From personal experience, we know that leaving a hot cup of coffee in room temperature cannot result in a frozen cup. Furthermore, as the model continues to run, the coffee would reach a point called *absolute zero*. Absolute zero may be more commonly known as zero degrees Kelvin, or -273 degrees Celsius. Temperatures cannot fall below this point, because this is when all heat has been removed.

These problems arise because the coffee cup model with constant heat loss is not a complete representation of what actually occurs. In reality, the difference between the coffee temperature and room temperature causes heat to flow from the coffee to the atmosphere. Thus, we must create a new model that includes these factors.

Negative Feedback Loops

Nothing in life increases or decreases at the same rate forever; most

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things tend to move toward an equilibrium. Negative feedback loops generate this stabilizing or goal-seeking behavior. In the previous example shown in Figure #2, the **Heat of Coffee** was lowered by the **Heat Loss Rate**, yet the rate remained constant. This relationship contains no feedback. The Stella causal diagram in Figure #4 below shows the interconnections between the level and the rate. As the **Heat of Coffee** goes down, the **Heat Loss Rate** also goes down. This is represented by the plus sign, showing that both move in the same direction. As the rate goes down, the **Heat of Coffee** lowers, *but to a lesser degree*. In other words, the slope of the **Heat of Coffee** gets flatter.

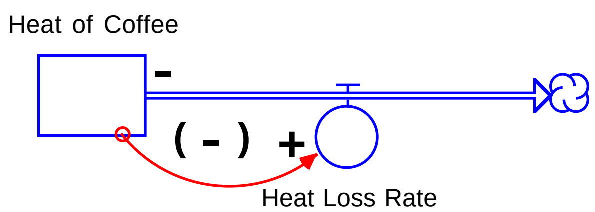


Figure #4 This is a STELLA causal loop diagram. This figure represents the structure that produces the stabilizing behavior that works towards equilibrium. The rate is dependent on the Heat of Coffee. Now, the Heat of Coffee cannot fall below the equilibrium point.

A More Realistic Model

The model in Figure #2 was very simple, with one stock and one outflow. However, we saw that the constant rate model was too simplistic, and thus it was incorrect. Most things and actions in this world are affected or depend on other factors. Figure #4 shows **Heat of Coffee** affecting **Heat Loss Rate**, and vice versa. While Figure #4 is a better representation of reality than the constant outflow model, it does little to show exactly how **Heat of Coffee** affects the **Heat Loss Rate**. A more complete model is shown in Figure #5.

Although this model is more complete, it still has only one level, **Heat of the Coffee.** This level is the number of calories in the coffee above those at zero degrees Celsius. In this model, the heat is initially at 10,000 calories. If there are 10,000 calories of heat in an enormous tank of coffee, the coffee would be rather cool. However, if the same number of calories were in a small coffee cup, the coffee would be much hotter. This is a hot cup of coffee.

The **Specific Heat** of the coffee is known as the amount of energy it takes to heat up one gram of water by one degree. In this case, the specific heat is equal to one.[4] The **Mass** has also been set equal to 100 grams.

In this model, the stock and flow are not independent of each other. The outflow, **Heat Loss Rate**, is driven by the discrepancy between the **Room Temperature** and the **Coffee Temperature**. The **Temperature Gap** causes the heat to flow from the coffee to the atmosphere, because heat tends to flow from high temperature to low temperature. In other words, the **Heat Loss Rate**, dependent on the **Temperature Gap**, lowers the **Heat of the**

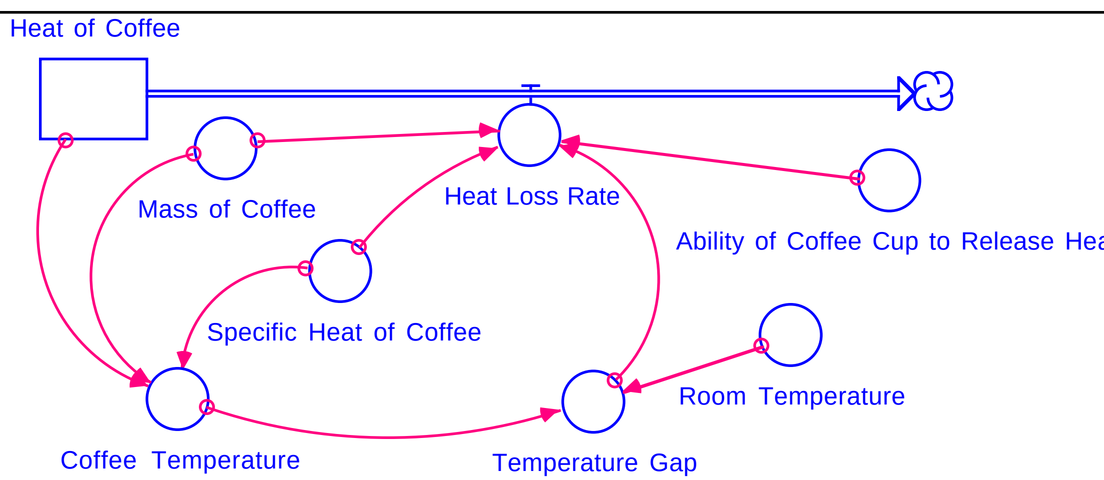
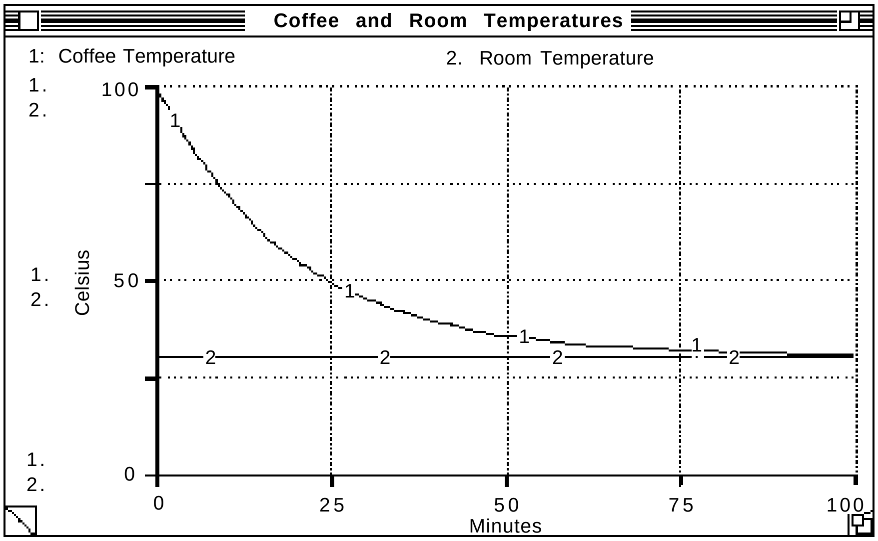


Figure #5 This is a revised and more realistic STELLA model which displays the negative feedback which is present in the real system. The Heat of Coffee and the Heat Loss Rate are the level and rate respectively. The Temperature Gap is the discrepancy in the model that drives the rate. The Coffee Temperature converts the heat units to temperature units. The Mass of Coffee, and Specific Heat of Coffee are converters that help translate the absolute measure of the Heat stock into its relative measure of Temperature. The Ability of Coffee Cup to Release Heat is another convertor.

Coffee and therefore the **Coffee Temperature**. This causes the **Temperature Gap** to decrease because the coffee is now cooler, but not as cool as the room temperature. Although the heat still continues to drop, it does so at a lower rate. See Figure #6. The coffee temperature falls by a lesser amount each time period until it reaches equilibrium at room temperature.



Figure#6A In this graph, the temperature drops asymptotically until it reaches equilibrium at room temperature.

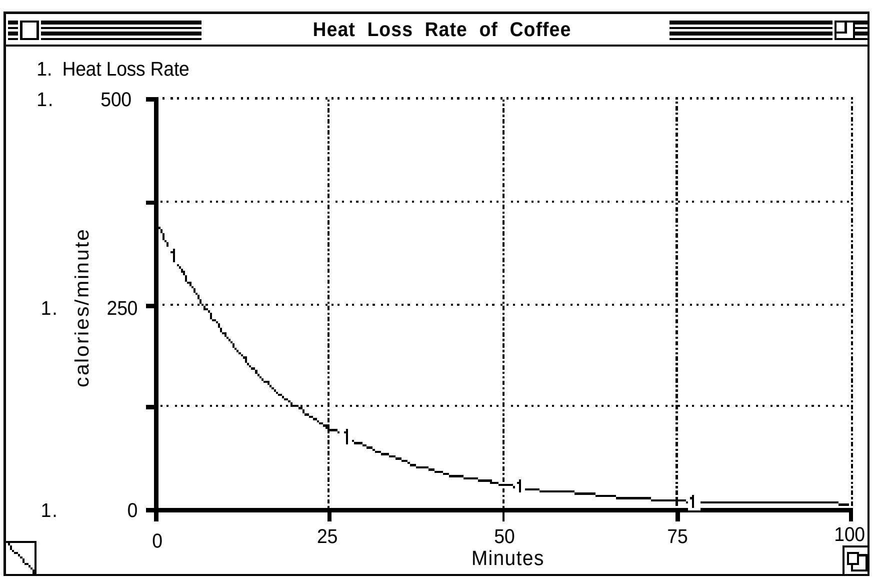


Figure #6B In this graph, the heat loss rate also drops asymptotically until the Heat of Coffee is in equilibrium with the heat in the atmosphere. The units calories / minute represent the number of calories lost each minute.

Because the **Temperature Gap** is the driving force of the **Heat Loss Rate**, the gap affects the rate the most when the **Coffee Temperature** is at its initial one hundred degrees Celsius. See Figure #6A. As shown in Figure #6B, the **Heat Loss Rate** is also the greatest initially.

The **Coffee Temperature** can be calculated through a simple conversion from heat to temperature. To derive temperature from **Heat of Coffee**, a conversion of units from calories to degrees is necessary. The equation in which temperature can be calculated is:

Temperature = Heat/ (Specific Heat*Mass)[5]

The units of the different factors in this equation are as follows:

<u>Temperature</u> : Celsius degrees
<u>Heat</u>: calories
<u>Mass</u>: grams

Specific Heat=Calorie/ (grams*Celsius degrees)

Since checking dimensional consistency is a method of confirming an equation, the units work out as shown below:

Celsius degrees = Calorie/(calorie/ (gram* Celsius degrees)) * gram

Celsius degrees = Celsius degrees

Another factor that affects the cooling rate of the coffee is the coffee cup itself. Some materials tend to retain more heat than others causing the coffee to cool slower. In addition, more heat will escape if the coffee cup has a large surface area exposed to the air, compared to the volume of the coffee. For example, two 100 gram cups of coffee are placed in the same room. Both cups are made of the same ceramic material. The first remains in the cup while the second is poured onto a plate. The second would cool faster, since more

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coffee is in direct contact with the cooler air. In this model, these factors are simplified into the converter called **Ability of Coffee Cup to Release Heat**. This coffee cup factor directly influences the rate of cooling. If this converter is equal to one, then the coffee cup releases the heat in the coffee very, very quickly. If the convertor is set equal to zero, no heat is released.

Conclusion

When considering a hot cup of coffee in a room at normal temperature, it is easy to believe that the coffee will cool. However, it is not quite as easy to discern how or why this behavior happens. Many tend to believe that the coffee temperature will drop at a constant rate by a few degrees each minute. Or in other words, they believe that the heat of the coffee has a constant outflow. This is incorrect, not only because the one-level constant outflow model goes into negative heat, which is an impossibility, but also because intuitively, most things in the world contain negative feedback loops that seek an equilibrium. In the revised model, the heat in the coffee escapes at a rate that is dependent on the difference between the room and coffee temperatures. The negative feedback loop in this model caused the coffee temperature to reach its equilibrium at room temperature.

Supplementary Ideas

This negative feedback loop and the resulting behavior does not apply only to a cooling cup of coffee. A draining bathtub and the half-life of radioactive elements have the same underlying structure. One possible exercise to teach this concept would be to experiment by heating a tea kettle, and then letting it cool while measuring the temperature every few minutes. By plotting the recorded temperatures, the student can see the behavior of the cooling for himself.

[1] Celeste Chung is participating in the System Dynamics in Education Project, under the supervision of Professor Jay W. Forrester. She is presently a sophomore at MIT, studying management science.

[2] STELLA (Systems Thinking, Experiential Learning Laboratory, with Animation) is a registered trademark of High Performance Systems, Inc.
45 Lyme Road, Hanover, NH 03755. 1-800-332-1202.

[3] Michael Shayne Gary. "D-4272-7 Mistakes and Misunderstandings: Examining Dimensional Inconsistency." 1992. System Dynamics in Education Project. MIT. 1 Amherst St. Cambridge, MA.

[4] Because coffee, is very close to water, the specific heat of the coffee is set equal to the specific heat of water. The specific heat of water is one.

[5] Watkins, Emiliani, Chiaverina, Harper, LaHart. General Science. Harcourt Brace Jovanovich. Orlando, Florida. 1989. p. 223-5.

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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Address____

Thank you!!

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