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A SYSTEMS VIEW OF NATURAL PROCESSES: TEACHING PHYSICS THE SYSTEM DYNAMICS WAY

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ABSTRACT: There exists a view of how nature operates—originating in classical continuum physics—which conforms completely to the core concepts of system dynamics. Simply stated, in the Continuum Physics Paradigm, physical processes are pictured as the result of the flow, the production, and the storage of some fundamental and easily visualized quantities—such as fluids, electricity, heat, and motion. If we base our teaching of physics on this paradigm, content matter (physics) and methodology (system dynamics modeling) form an organic unit. Unlike with the conventional mechanistic view of physical processes—where system dynamics must remain a method artificially superimposed on a non-systemic science—physics will itself have a systemic structure, and in return will help foster systems thinking in other fields. Moreover, the Continuum Physics Paradigm can be used for physics instruction at virtually any level of students' maturity or formal sophistication, ranging from primary school to graduate school. Last but not least, physics joins humankind's endeavor of making sense of the natural, technical, and social world on the basis of a unified image.

Images of change

Look at the natural world out there. How does it operate? What makes this great dynamic engine called the universe, including our beautiful planet, tick? Answering these questions will lead us right to a systems structure of physical sciences.

Everything flows… The most directly accessible and visible processes on our planet are those of the flow of water and air. Together, these phenomena create a good deal of what we see happening around us. The atmosphere, and the oceans and rivers, present us with the unique opportunity to witness how nature operates at the deepest level. Water and air flow to create some of the most important and beautiful phenomena. Indeed, we say that the phenomena are the result of this flow (Fig.1).

Other quantities flow as well, adding to our list other important classes of phenomena. Heat flows from the depth of the Earth, or with the help of fluids from point to point at the surface of our planet, or from the Sun out into the solar system. Electricity flows as well, giving rise to electric (and magnetic) processes. Technical appliances add much to our experience with electrical phenomena, and we explain the processes again in terms of the flow of electricity.

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British Petroleum Is Not Jackson Middle School: Different Best Modeling Practices for Different Environments

by Ron Zaraza, Tim Joy, and Scott Guthrie

Educators attempting to bring the concepts of system dynamics into the classroom have always looked to the experiences of system dynamicists for guidance. Until recently, the only training in system dynamics focused on its traditional policy and business uses, so teachers followed the ideas of the leaders in the field with great faithfulness. The importance and impact that system dynamics pioneers have had in the development of educational uses of systems is evident in the role people such as Jay Forrester and George Richardson have played at the K-12 Systems conferences. Their participation in the K-12 systems in education listserve (k12sd@sysdyn.mit.edu) is further evidence of their interest and commitment to the use of System Dynamics in the K-12 environment. Thus, it is only appropriate that a discussion they were involved in on the list–serve provided the motivation for this paper.

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EDITORIAL . . .

Happy New Year! I hope all of you have started back to school with new vigor after the holidays. The break is good for reflection and perspective. Although I did not get to Tim Joy's holiday reading (sent to the listserve), I am still hoping to pick it up as I sneak my 15 minutes after lights should be out.

For those of you who have not yet joined the K-12 listserve, I heartily recommend it. (To subscribe, send e-mail to k12sd@sysdyn.mit.edu) We had two excellent discussions this fall, one centered on beginning concepts for system dynamics in K-12, and one on transferability of concepts. The summary of the discussion about the first question was in last month's newsletter and the summary for the second will be in the next newsletter. January's question will be on line soon.

"Updates" contains an article by high school students about using modeling to get across the seriousness of drinking and driving. It is exciting that students are starting to visibly use the tools in real life situations.

Finally, look at the beginning information on the Systems Thinking and Dynamic Modeling Conference in 2000. It will be held in a lovely lodge in the Columbia River Gorge, 45 minutes from the Portland, Oregon airport. Make your plans to attend now!

Keep in touch. The more we hear from you, the better we like it.

Lees Stuntz (stuntzln@tiac.net)

UPDATES . . .

STUDENTS TAKE A SYSTEMS APPROACH TO DRINKING AND DRIVING

Stephany Yerger, Class of '99, La Salle High School, Milwaukie, OR

Alcohol kills five times more people than cocaine, heroin, marijuana and all other illicit drugs combined.

Everyday, people of all ages use or abuse alcohol. The social costs of caring for abusers often prevail over the cost of educating our youth on the issues of drinking and driving, and each year hundreds more become addicted, often taking to the road while under the influence. In conjunction with a Religious Studies III Systemic Transformation Action Plan and the 1998 SyM*Bowl competitor, Shanna Prevé, Jon Barbur, and I set out to create a tool for hands-on alcohol education using STELLA.

The Waters Foundation's generous grant to La Salle High School has enabled us, over the past year, to take a System Dynamics class where we use STELLA to study how things change over time. As a part of the second semester, we had the opportunity to study and develop a model for the SyM*Bowl. Unlike the previous classroom tutorials and guided model building, our preparation, research and actual model creation was done independently. Because our Religious Studies group was in the process of founding a Students Against Destructive Decisions (S.A.D.D.) chapter at La Salle, the idea for an interactive, visual simulation depicting how alcohol consumption impairs a driver came to mind. Wrongly assuming that this would be a simple task, we decided to pursue the idea for our SyM*Bowl project.

Like the drug absorption/elimination models that we had studied earlier, we assumed that a format for alcohol oxidation existed in the STELLA world. Indeed, we discovered a model format, but it was based around false data and a misunderstanding of the oxidation process. So, from scratch, we summoned up our model building skills and collectively began a model that has yielded us much more personal satisfaction than we ever expected.

The thought process was complicated, as we all had to agree on one working idea. The hours of research and time spent working together left us with a new definition of the word *teamwork*. We pulled together when it counted, though, and after nearly a month of hard work, the final copy of the paper and model "How Does Alcohol Affect a Driver's Reflex Action Time?" successfully printed.

The simplicity of the model makes its hands-on use easy to understand. Although there are many factors that affect the reaction to drinking alcohol each individual will have, we narrowed it down to gender, body weight, amount of pure alcohol consumed, and time. After the level of intoxication for the virtual person is calculated, we are able to apply the physics portion of the model, which displays how each drink of alcohol slows one's normal reflex-action time of .75 seconds. Ultimately, we will add how that, in turn, reduces the car's capacity to stop in the event of a problem.

The day of the SyM*Bowl competition came and went. We received honorable mention for the social significance of our project, but to our disappointment, we did not place. Our inability to make it to the final round of judging stemmed from our relatively small amount of STELLA experience and our model's lack of one key part: the

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Teaching Physics the System Dynamics Way

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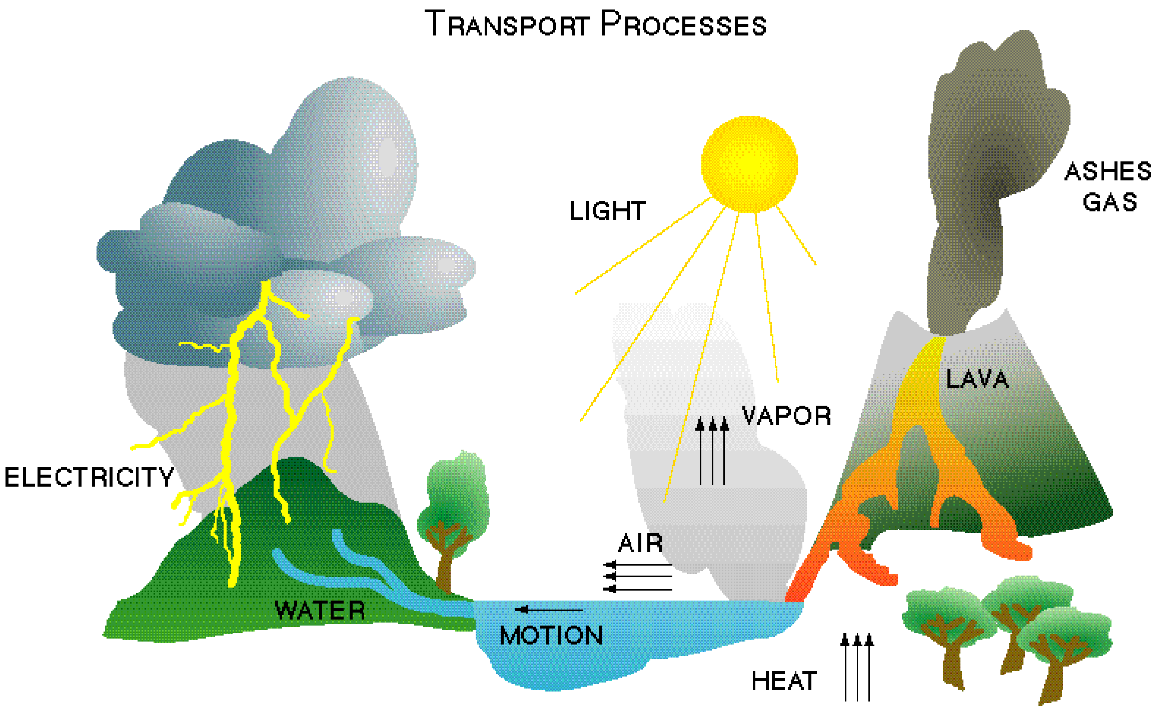

Figure 1: A large part of the phenomena we know from every-day life can be explained in terms of the result of flow processes. We transfer what we observe in the case of water and air to those fields which are beyond our direct sensory experience, such as the flow of heat or electricity.

These last two examples are important in that they prepare us to talk about the flow of invisible quantities as if they were water and air. The importance of this point cannot be overstated. First, we learn how to deal with "stuff" we do not see, we learn how to create images for processes which are governed by "imponderable" quantities. Second, it is the source of a unified description of natural processes. How should we ever arrive at a unified view of natural, technical, and social processes if one of the great old subjects presents itself as a flea market of phenomena and concepts—where thermodynamics, mechanics, electricity and magnetism, and fluid dynamics each form a separate world?

Let us take the unifying view seriously and extend it to the motion of bodies. Consider how a storm near New Zealand can produce high surf at Oahu's south shore—as reported in my favorite headline of one of Hawaii's newspapers in the Summer of '95. The winds down under have momentum, or, as Newton might have said, they have an amount of motion. By blowing over the ocean, they impart part of their motion to the water. Now, the water is not set in motion, it does not flow to Hawaii. Rather, momentum is transported through the water all the way to distant shores where it can be picked up by experienced—and not so experienced—surfers. Note, motion travels through bodies, just as heat and electricity do.

…or is produced and destroyed… Flow processes are only a part of what is hidden behind the changes observed in nature. The other great source of change are the processes of production or destruction of some of the same quantities which can flow (Fig.2).

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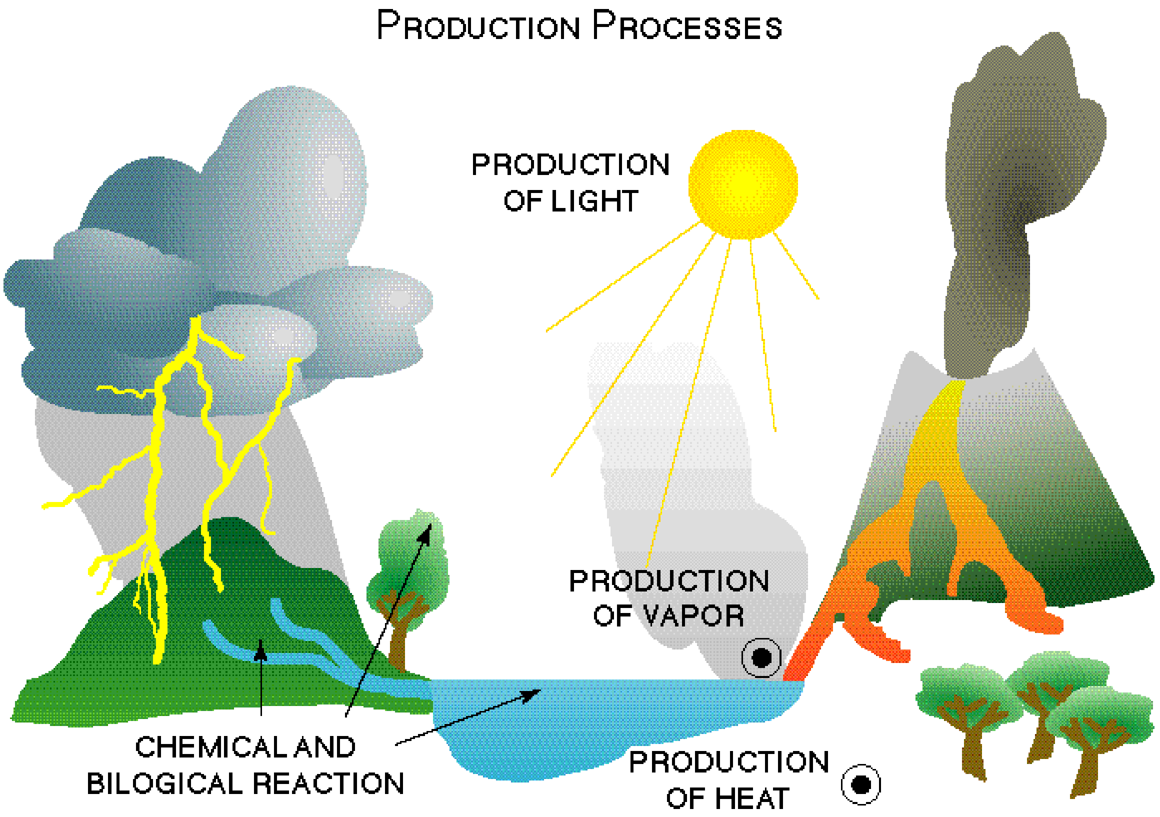

Figure 2: Processes may also be the result of production or destruction of some of the physical quantities. In particular, amount of substance and heat are not conserved, and their production and destruction has to be considered in physical processes.

Substances such as water and air, CO2 and minerals, and the objects made out of them, are subject to chemical change—they undergo chemical reactions. Some of the substances disappear, and new ones arise. We even can add light to the list of "substances" which can be created and destroyed.

There is one more centrally important case of production: heat is produced in the multitude of irreversible processes we know—fire, friction, radioactive decay, the absorption and emission of light, and the flow of electricity, substances, and heat itself. Since heat cannot be destroyed, the amount of this quantity can only increase.

...or is stored. The same quantities we imagine flowing through space, or being created and destroyed, must occupy space. They are contained in bodies or regions of space out of which, and into which, they are flowing. In other words, they can be stored. Storage, flow, and production together are the source of change in nature.

Driving forces for change. Why do processes of change occur? Again we can derive a simple image from the case of water and air. By itself, water flows downhill. We need a difference of levels for this to happen. Air flows from points where the pressure is high to those where it is lower. Pressure therefore serves as the level quantity associated with the flow of substances. [Note, that the word "level" denotes a quantity altogether different from what in many system dynamics circles is called a level. The levels whose differences serve as driving forces are not the same as accumulating quantities for which we would introduce stocks.]

Each class of phenomena has its own level and driving force: pressure for fluid flow, electrical potential for electricity, temperature for heat, speed for motion, and the chemical potential for chemical change.

Energy. Energy is associated with all the processes mentioned. It accompanies all of them, which means that it is not specific to any of them. There is only one quantity called energy—not the myriad “types of energy” known from classical physics instruction.

Energy is released when one of the accumulating quantities (fluids, electricity, heat, motion) flows from a higher to a lower level (thin horizontal arrows labeled I—for current—in Fig.3), and it is bound if the quantities are “pumped uphill.” The fat vertical arrows in Fig.3 labeled P—for power—denote the rate at which energy is released or bound. Energy can be transferred from system to system (fat horizontal arrows labeled IE in Fig.3), and it can be stored in systems. Moreover, it cannot be produced or destroyed. These are all the properties of energy needed to explain what is happening in nature. Energy is not used, nor is it generated, nor is it transformed.

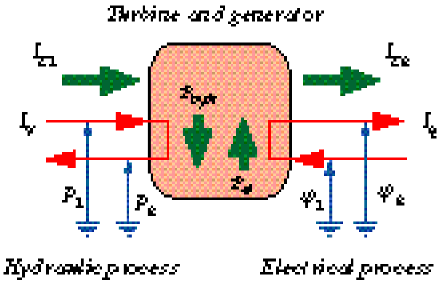

Figure 3: Energy can flow into or out of systems (IE). It can be released or bound (P) if fluids, electricity, heat, or motion flow either “downhill” or “uphill.” And it can be stored in systems. The thin vertical arrows denote levels or potentials.

Note that none of the quantities introduced to explain physical processes—fluids, electricity, heat, motion—is energy. Energy is altogether different. When the fundamental quantities flow, or are produced or destroyed, energy accompanies the process.

An Example: The flow, the creation, and the storage of heat

Fluids, electricity, heat, and motion are introduced to account for what happens in dynamical processes in nature. Their flow, production, and storage are held responsible for the processes. Witness how easy it is to create the image of the role of these quantities.

Take the case of heat. We have very valuable everyday knowledge of the properties of heat. Heat is responsible for making stones warm, or for letting ice melt, and it is contained in these same bodies. It flows into and out of them. It can be created, but it cannot be destroyed. Indeed, we need this latter property to account for the irreversibility in physical phenomena. Moreover, when flowing from points of high temperature to points of lower temperature, energy is released which may be used to drive a heat engine. This is Carnot’s image of how heat engines work.

Now combine the fundamental properties—heat can flow, it can be produced, and it can be stored—into a law of physics: laws of balance tell us that the sum of all currents of heat and of the rate of production of heat determines how fast the amount of heat in a body is changing. Put this statement into the form of a system dynamics diagram, i.e. the appropriate structure of a stock and some flows (Fig.4), or turn it into an equation. What you have just obtained is the most general form of the second law of thermodynamics—the law of balance of entropy.

The quantity I have called heat is entropy. No fussing about a “strange” and “wonderful” quantity “ingeniously invented” by a “most beautiful physical theory”—thermodynamics. On the basis of physical systems thinking, and supported by system dynamics tools, kids can create this image which is the starting point for an investigation of dynamical thermal processes—reversible and irreversible. If you wish to know more about this story, have a look at my book, The Dynamics of Heat (Springer, 1996).

A unified view of natural processes

Since all phenomena are explained as resulting from the flow, the production and the storage of certain quantities, we can expect strong similarities between different fields of

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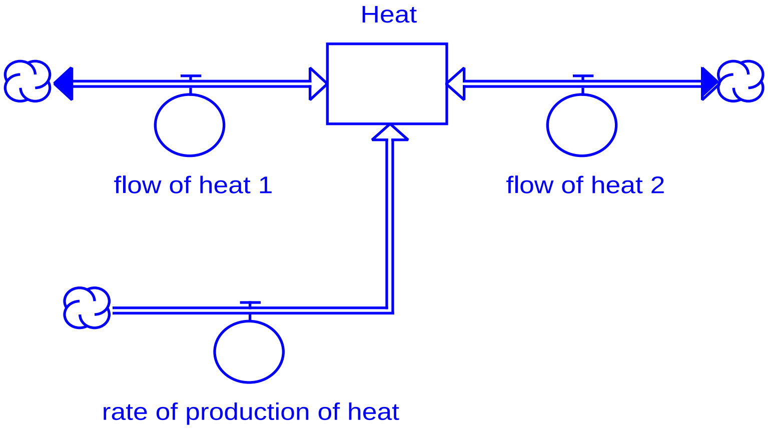

Figure 4: The system dynamics representation of the law of balance of entropy—the most general form of the second law of thermodynamics—ready for use in the computation of dynamical thermal processes. Note that transfers (currents) and rates of production are denoted by the same symbol (flows).

Teaching Physics the System Dynamics Way

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physics. The source of the structural analogies can be found in the existence of what may be called a “substancelike” quantity and an associated level for every fundamental type of physical process (Table 1).

Table 1: Comparison of quantities for different fields

Class of phenomena	Quantity which flows and is stored	“Level” quantity whose difference is responsible for flow
Hydraulics	Volume or amount of substance	Pressure or chemical potential
Chemistry	Amount of substance	Chemical potential
Electricity	Electrical charge	Electrical potential
Heat	Heat (entropy)	Hotness (temperature)
Gravity	Gravitational mass	Gravitational potential
Translation	Quantity of motion (momentum)	Velocity
Rotation	Angular momentum	Angular velocity

The table entries can motivate us to search for and to develop a simple unified theory of physical processes applicable to physics instruction. For example, we find that in each field there exist elements having analogous functions (see Table 2). Obviously, system dynamics structures of such systems must all look essentially the same.

System dynamics modeling in physics

You all know system dynamics, so I can be brief with my remarks about how to apply system dynamics modeling within the structure of physics which I have created here. Obviously, we start with thinking about how nature works by formulating the laws of balance of the appropriate quantities which flow, are produced, and are stored. The laws of balance are represented by structures of stocks and flows. Hardly anywhere else do we get such a clear image of the importance and the meaning of stocks and flows as we do in physics—if we are prepared to look at nature through the eyes of a “continuum physicist.”

Table 2: Simple system properties

Class of phenomena	Capacitors	Resistors	Inductors
Hydraulics	Containers and pressure vessels have hydraulic capacitance	Fluids and pipes are systems with hydraulic resistance	Fluids in pipes have hydraulic inductance
Electricity	Electric capacitors have capacitance	Resistors have resistance	Inductors have inductance
Heat	Entropy capacity	Entropy transfer resistance	
Translation	Inertial mass is the momentum capacitance	Friction leads to resistance	Springs have inductance
Rotation	Moment of inertia is the angular momentum capacitance	Friction leads to resistance	Rods have inductance

Once we have the stocks and flows, i.e., the laws of balance, we have to determine the flows. Physicists and mathematicians speak of the need for formulating special laws, material laws, or constitutive relations. Children equipped with STELLA know intuitively that is what is required. We ask which other important quantities the flows and the rates of production depend upon, and we slowly create the structure of (feedback) relations resulting in a finished model of a physical process.

Systems and process thinking in physics

Can physics enhance systems thinking? Obviously, it can only do so if it is a systems science itself. If it is presented as such it can indeed increase our understanding of system dynamics structures and of the process of modeling according to the system dynamics methodology.

In physical systems thinking, feedback loops arise naturally as a result of the modeling process. We may start our thinking by first asking about the existence of such loops, but the practice of modeling in physics suggests that there are large areas of applications where thinking in terms of the flow, the production, and the storage of the fundamental quantities should precede these questions. In other words, thinking about processes complements systems thinking.

Also, the phenomenon of induction and the geometrical relations known from kinematics teach us that there are special laws which specify the time rate of change of a physical quantity rather than the quantity itself. To get the quantity, we have to integrate its rate of change. This mathematical operation is not a law of balance—and therefore should not be represented by structures of stocks and flows. Although there is no difference between a law of balance and the process of integrating a rate of change on a purely mathematical level—the resulting equations have the same structure—there is a fundamental difference between these two classes of laws which we should never forget. Physics points out this fact, and a dose of physical systems and process thinking may even help us in streamlining our thinking when it comes to applications in non-physical and non-technical fields. Finally, this suggests that creators of system dynamics tools may wish to think about making a distinction between structures of stocks and flows, and simple integrators of rates of change, i.e. structures of “states and rates.” [Note that I do not use the term “levels and rates”, since levels are different quantities in physics.]

System dynamics in physics and beyond

At Technikum Winterthur, Werner Maurer and I have been designing introductory college physics courses based on the Continuum Physics Paradigm for the last 15 years. In 1987 we discovered STELLA and the system dynamics methodology and realized that we had been working on a system dynamics structure of physics all along. Step by step we integrated system dynamics modeling in our courses, and we now use it in a combined modeling and experimental lab—an integrated learning environment—to accompany the basic course on the physics of dynamical systems (the first of two years of physics instruction in the engineering departments of our school). In addition, system dynamics diagrams are used frequently in discussions of physical processes in lectures and recitation.

We have been involved in teaching college preparatory physics courses, and we have trained upper secondary school teachers who teach prospective engineering students. The enthusiasm with which they have applied system dynamics modeling in the integrated learning environments has been positively refreshing. Currently we are working on a textbook for high school physics which makes use of the approach described here.

Shortly after Werner Maurer and I started on our project, Martin Simon joined us, and he and I have been busy designing solar energy courses which make heavy use of modeling of dynamical systems. Students trained in the physics of dynamical systems take very easily to a methodology which is becoming more and more important in engineering work, and they have been using Stella and other modeling software in novel ways in their diploma thesis work.

Lately, we have been able to build up a graduate course on general system dynamics modeling bringing together students from different fields—so far mostly from engineering, the sciences, business and management. Martin Simon is particularly interested in applying what we have learned to business process modeling. In short, our early involvement with a form of systems physics is beginning to pay off in many other fields as well.

Background material

An in-depth study of the dynamical structure of thermal processes, including a discussion of the unified view of physical processes described here, can be found in H.U. Fuchs, The Dynamics of Heat (Springer-Verlag, New York, 1996). Recently, I have finished three reports which detail the approach developed by Werner Maurer and myself (The Continuum Physics Paradigm I–III, Technikum Winterthur, Winterthur, Switzerland).

System dynamics tools have been used for modeling dynamical physical processes before. Unfortunately, most examples do not do much justice to physics or system dynamics (B. Hannon and M. Ruth, Dynamic Modeling, Springer-Verlag, New York, 1994, Chapter 30). Much too often, it is declared that physics is “different” in that the differential equations governing the processes are already known, and we therefore can (ab)use system dynamics tools to simply solve these equations. However, lately, some serious attempts have been made to include system dynamics modeling in physics instruction and thus rejuvenate the learning and teaching of this science (H.P. Schecker, Modeling physics: System Dynamics in physics education, The Creative Learning Exchange 5(2),1–8, Spring 1996; H.P. Schecker, Physik – Modellieren, Ernst Klett Verlag, Stuttgart, 1998; CC-STADUS Project, http://www.teleport.com/~sguthrie/cc-stadus.html). Still, to my knowledge, the projects do not make use of a general systems view of physical processes, and thus forgo much of the power of system dynamics in physics education.

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Note: This article is called ***PHYSICHF*** *on the website and List of Materials.*

Students Take Systems Approach to Drinking & Driving

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feedback loop. The accuracy of the data produced by the model, however, was never in question. Looking back, we now understand some of our model building problems and we understand how to change a lot of them.

Over the summer, the Oregon Partnership, a non-profit drug and alcohol prevention organization, and the Oregon Department of Transportation, have awarded the three of us a grant to develop the model so that it addresses a few other key factors: mixed drinks versus pure alcohol; persons who weigh under 100 lbs; driving a motorcycle, riding a bike, or walking; the effect of minute amounts of alcohol; and various sizes and types of vehicles. We plan to keep the model fairly simple because we will be using it to educate high school health classes, as well as younger children; consequently, it needs to be at a level of understanding that doesn't require a STELLA interpreter. Our turnaround time for these adaptations is six months.

During this next semester, we have been asked to use the model to present at meetings before the Governor's Council on Drugs and Alcohol, to lobby for legislation that supports a legal limit lower than .08 blood alcohol concentration, and to continue its use in health classes in our school. Our first experience with presentations of the model to our peers was very recent as we helped to introduce an extended unit on Drugs and Alcohol to the Sophomore Health classes.

The three of us also have the job of recruiting up to four new students from our school who are familiar with the program and whom we believe will honestly be able to implement our ideas. The new students will follow in our footsteps next year when we move on to college, using the grant money to take the new and improved version of the model into local elementary, middle and high schools to help educate kids on the very real dangers of drinking and driving. It is likely these new modelers will further adapt the model, if not build other models, such as the long-term effects of alcohol use on a liver.

The opportunities provided to us have been enormous, and we intend to continue our endeavors to help educate our peers on the dangers of drinking and driving. The knowledge that we have the power to make a difference has allowed us to taste the sweetest of all successes.

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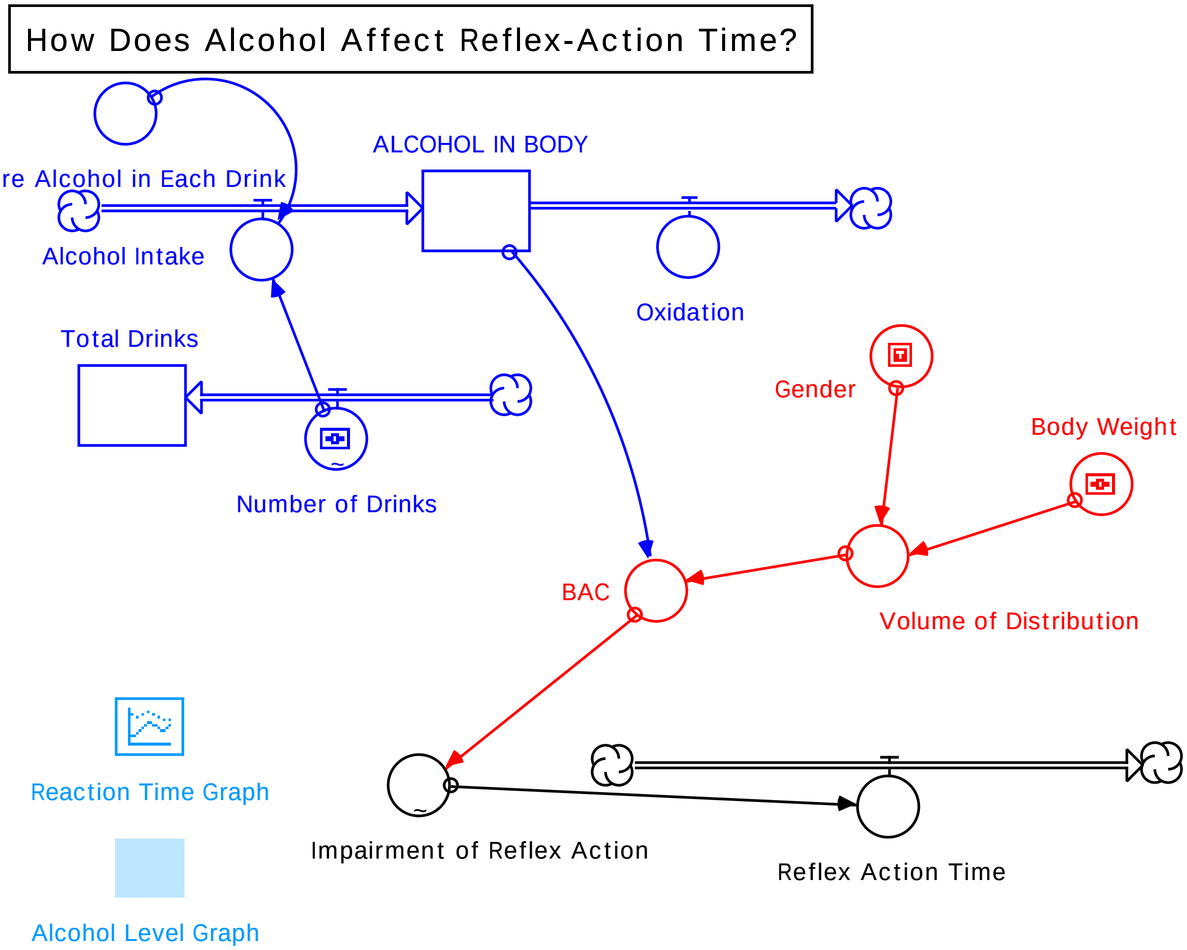

Best Modeling Practices for Different Environments

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The question of "best," "preferred," or "most probably successful" practice for model construction became the focus of a discussion. This was a result of a question about the possibility of modeling a high school as a system. George Richardson observed that "Since the early days of system dynamics it has generally been agreed that one can not build a model of a system (like a high school), but instead one must take a problem or interrelated set of problems as the focus of the model."[1] He suggested that modeling the system, rather than a well defined problem within the system, would be difficult, if not impossible. This response provoked a series of exchanges lasting about a week, in which some participants asserted that the need to focus on problems, rather than a general system, was unnecessary, while most supported Richardson. An interesting insight came from Jay Forrester, who, while supporting Richardson, noted that changing George's assertion to "it has generally been true"[2] might well resolve the issue, since it is a less absolute statement. The issue, however, was not one that participants were willing to drop.

It quickly became clear that the underlying problem was understanding model conceptualization. What are the necessary (or at least useful or most probably successful) steps or components in conceptualizing and constructing a model? As the discussion developed, Richardson shared the components of model conceptualization he uses with his students:

Problem focus*
Problem Dynamics*
Context*
Audience*
Model Purpose*
Model Boundaries
    –temporal
    –conceptual
    –causal
Aggregation
Reference Modes
Initial Policy Options
Model Sectors
Important processes in each sector
Important levels and associated rates in each process and sector
Apparently important feedback loops
Next steps[3]

The components identified with an asterisk (*) are considered to be the most crucial to the modeling process.

Richardson's components focus attention on a problem, not on a system. Listserv comments from other participants who are actively involved in the modeling of dynamic systems tended to support the emphasis on problem identification and delimitation as primary factors in successful model building. This approach to model conceptualization has also seen wide-spread use in educational applications of system dynamics. It is the ability of system dynamics to address interesting and exciting problems outside the reach of conventional tools and methodology that often first attracts teachers. Among members of the CC–STADUS/CC–SUSTAIN core team, most initially saw system dynamics as a better way to teach and solve problems in mathematics, physics, history, biology, and other disciplines. This focus is consistent with the "best" or "common" practice of focusing development of a model on a clearly defined problem. It is also an entirely appropriate use of system dynamics in education.

The educational materials developed at the K–12 level usually follow this approach. The materials are designed to address a clearly defined problem, develop a model to illustrate it, then use the model to obtain actual numerical results. Several curriculum packages available from the Creative Learning Exchange provide excellent examples of this approach to using systems dynamics. The Radioactive Decay package consists of preliminary text and models about linear and exponential growth and decay, simple models and questions about radioactive decay, and finally, exploration of radioactive decay sequences using both a model and questions. The entire curriculum package is defined by focusing on the problem of radioactive decay. Activities develop both the concepts and models, providing an alternative to traditional approaches. The final activity, in which students construct a 3–element radioactive decay sequence, includes a model that yields numerical results which cannot be obtained with the mathematics normally available to K-12 students. Thus, the models are used to solve increasingly complex variations of the basic problem.

A variety of predator–prey relationships are also examples of the problem–focused use of modeling. Because the interrelationships are impossible to describe quantitatively without very advanced mathematics, they have frequently been subjects of dynamic models used by teachers. They provide the only vehicle which is able to explore the problem of how species interact and yield numerical results. They are also excellent examples of the problem–focused modeling activities that constitute the vast majority of models and curriculum currently in pre–college use.

Since content–specific ideas are an important part of the curriculum in every discipline, the use of system dynamics as a problem solving tool is an appropriate and powerful use. However, it is important to guard against system dynamics remaining only a tool. For system dynamics to have its maximum impact on student learning, it is necessary to look at the real potential of systems concepts. Teachers repeatedly justify the use of models and system dynamics as a way of "getting students to ask better questions." The specific–problem oriented models do develop this ability to some degree. However, the real power of system dynamics is its potential to equip students with the ability to look at real–world systems and begin to ask questions that will build an in depth understanding of the system. Learning through system dynamics can develop the critical thinking and analytical skills that will allow students to make intelli-

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gent evaluations about the complex problems and systems they will encounter. In order to maximize the possibility for this type of intellectual growth, modeling and systems concepts must not focus only on narrowly defined problems. Much broader and ambiguous problems can and should be used as a starting point, since this is the pattern students encounter in their daily lives.

Models that develop the questioning skills are often not problem–specific, that is, they do not look at well defined and delimited problems. Instead, they tend to be models painted with a "broader brush," lacking in well defined boundaries or details. Looking to the "best" practice of system dynamicists, teachers often reject such models because they are not "accurate" enough, because they don't allow students to draw definite conclusions about clearly defined questions, because they don't give enough "facts." The models are often described as "ambiguous." These types of models often trigger criticism of the model and even the idea of modeling.

An experience that a number of Portland (Oregon) area teachers have had illustrates this type of situation. Global studies is a freshman (9th grade) course taught in many local schools. One of the unifying ideas that teachers often use in this class is the role population growth plays in the difficulties experienced by developing nations. To explore this, they use a simple population model with a single stock, *population*, a *births* inflow and a *deaths* outflow. The model produces simple exponential growth. When run for a period of a hundred years, the results are dramatic and frightening. Nations like Malawi show a growth in population of 2200% or more.

Almost inevitably, the students react to the model by talking about the horrible situation that the people will find themselves in. Often the teacher gives them a deceptively simple assignment: develop a policy that can be implemented to prevent disaster. The result is unrealistic, and not satisfying. Policies show little understanding of the system, because the system hasn't been explored. This lack of realism may motivate teachers to step away from the use of models. The problem is not with the model, but with the educational use of the model. Much greater benefits can be gained if the simple model is seen as the "doorway" to the system. Stopping at the door yields little knowledge. Going through it and exploring is riskier, but can yield great benefits. This riskier path is also followed by some teachers.

In most classes, one or more students react negatively to the model results. They say that the situation will not develop as modeled. The criticisms they express vary, but frequently include:

The birth rate won't stay that high. (for a variety of reasons)
The death rate will increase. (for a variety of reasons)
There will be massive starvation.
They will add more farmland.
They will practice birth control.
They will emigrate.
They will import food.
They will impose family planning.
They're not that stupid!

These comments can present a teacher with an opportunity to explore the system in greater detail, to step fully through the door. This exploration begins with questions about the comments. What are you assuming? What do you know? What do you think? What other information do you need? Where can you find the information? (Note the similarity to Richardson's components!)

These questions lead to a variety of activities. Students can do individual research about important factors that are revealed by both teacher and student questions. They can explore interconnectedness of the topics and questions. Further modeling is a possibility, either by students, the teacher, or a cooperative effort. Of course, each of these activities can initiate the cycle all over again. The choice is up to the instructor. The result, however, is an appreciation for the inherent complexity of most problems we encounter. Rather than being surrounded by simple cause–effect relationships, students are faced with increasingly complex situations in which small actions can have large reactions. This pattern leads to in depth learning, as well as initial experiences in exploring a system. The understanding of system dynamics grows more dramatically than in problem–focused activities. System dynamics concepts become an implicit part of the syllabus, rather than a tool for learning content.

This approach to using system dynamics is both riskier and more time intensive, but has the potential of greater gain. When the progress of the course is defined by the questions students ask, where the class is going is uncertain. Following the student's interest may increase student involvement, but it can also expand the time spent in a single area. What makes the approach even more difficult is development and selection of suitable "initial" models. There are few examples of such models to get teachers started. Systems suitable for exploration exist, but emphasis has been in the direction of more clearly defined problems. It is clear that major efforts must be made to identify systems and additional questions that lend themselves to this approach before this alternative use of systems can grow beyond a few practitioners. Once the number of such simple models and curriculum materials grows, more teachers can begin to pursue systems–focused model use as well as problem–focused modeling.

Clearly in education there will ultimately be two distinct "best" practices in modeling. One, following the widely accepted practices of traditional systems modeling, focuses on well defined problems, developing models that build a detailed understanding of the problem. The other appears to be almost diametrically opposed. It looks at systems in the broadest sense as an initial step, building understanding of the system over time. There is no well defined problem. The exploration of the interconnectedness among and within systems itself is the "problem." These two different practices reflect the fact that the use of systems in education addresses different needs than in traditional system dynamics. While solving and explaining defined problems is important in both education and traditional uses of system dynamics, education has a larger and more vital task—development of thinking skills. System models that generate more questions than they initially answer may well be the most powerful "tool" for developing this most important of skills. The transition to use of systems concepts in daily life is quick and obvious. Even system dynamics novices find it difficult to watch the evening news or read a newspaper without wondering how businesses/governments/individuals can propose and implement simple solutions to what are obviously problems arising in complex systems. Experiencing that same kind of situation in classes will build that realization in students.

The two "best" modeling practices actually complement each other. Systems–focused models are inherently simple in structure, serving as "triggers" for the questioning process. Their purpose is not to address problems, but rather to expose their presence in a system. Problem–focused models are designed to answer well defined problems. Frequently, the system–focused models allow students to generate more specific problems that can be the focus of models. Even if models are not used, system concepts are focused on the questions and problems revealed by discussion of the systems models. Extensive work is being done in this area by Scott Guthrie and Megs Patton of Wilson High School (Portland, OR), who are teaching a Science-Technology-Society/World issues course using system dynamics. They report remarkable development of insights into complex issues by high school juniors and seniors.

With the realization that the purposes of system dynamics in education are more varied than in traditional system applications, it is possible to wonder whether or not it is possible to define the components of model conceptualization for educational uses as George Richardson has for general systems work. Returning to his components, it is clear that he has already done the task for educators. His components for general systems work are identical in problem–focused educational modeling. Even for those very different system–focused models, his components work quite well. What remains is a matter of definitions or clarifications. Looking at developing systems and thinking skills in students, Richardson's "problem focus" becomes a broad rather than a spe-

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2000 ST&DM CONFERENCE

The next Systems Thinking and Dynamic Modeling Conference will be held June 25-27, 2000, at Skamania Lodge in Stevenson, WA, just 45 minutes east of the Portland, OR International Airport.

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Work supported by the Fund is to be available for distribution through the Creative Learning Exchange and any other channels that the author arranges.

The Fund honors Gordon Brown, who pioneered the theory and practice of feedback dynamics and engineering control systems at MIT in the 1940s. Brown went on to be head of the Electrical Engineering Department and Dean of Engineering at MIT. During retirement, he devoted energy and skillful leadership to bringing system dynamics into the Catalina Foothills school system in Tucson, Arizona.

Address applications, with an outline of the proposed project, to:
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Best Modeling Practices

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cific problem. Exposing and exploring the interconnectedness of a specific system rather than one problem in the system becomes the focus of the model. “Model purpose” becomes an emphasis on raising questions rather than answering them. All other components transfer to the different approach with little significant change. The components of conceptualization truly are generic, with only the context changing. They serve as a useful guide for both “best” practices in education.

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[1] George Richardson in a message to the K–12 listserv dated 12/31/97

[2] Jay Forrester in a message to the K-12 listserv dated 12/31/97

[3] George Richardson in a message to the K–12 listserv dated 1/2/98

References

1. Forrester, Jay W. 1985. “ ‘The’ model versus a modeling ‘process’,” System Dynamics Review. 1 (1): 133–134
2. Richardson, George P. (Editor), Modeling for Management: Simulation in Support of Systems Thinking (International Library of Management). Dartmouth Pub. Co., 1996

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