the Creative Learning EXCHANGE

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SODA BOTTLE WATER ROCKETS: BUILD THE ROCKETS AND THE MODELS

Prepared with the support of the Gordon Stanley Brown Fund by Martha A. Lynes with Debra Lyneis

Although this article (excerpted from the full text) describes using bottle rockets to teach concepts in high school physics, it is a good example of physical experiments followed by the use of system dynamics to understand the conceptual framework. This curriculum could be adapted for use in younger grades especially with the use of the resources noted at the end of the article. For a complete copy of the curriculum, please go to our web site- sysdyn.mit.edu/cle/.

In this unit, high school physical science and physics students design, build, and launch soda bottle water rockets which whoosh off the launch pad trailing a spray of water. Then, after an introduction to the basic principles of system dynamics and STELLA modeling, students build a series of computer models leading up to a model of their soda bottle water rocket systems. The rockets provide for real-world, hands-on, minds-on project-based learning, while the computer modeling gives students a deeper understanding of the dynamic relationships among the factors that govern the behavior of the rockets.

This paper will describe the lessons and the models, and how they can be adapted for use with high school students of varying ages and ability levels. The complete STELLA models are included. Although this is a high school physics unit, the introductory modeling lessons, the modeling suggestions, and the learner-centered approach can apply to other grade levels, and subjects as well.

Background : The Students

The students who worked on the soda bottle water rocket unit were freshmen and seniors in both honors and standard level physical science courses at Algonquin Regional High School in Northboro, Massachusetts, a town about 25 miles west of Boston. The unit supplemented their study of motion and force. None of the students had any prior experience with system dynamics or STELLA modeling.

Despite their inexperience and a wide range in their academic and math abilities, all of the students could be successful in this project. Everyone's rocket flew, everyone's model eventually worked, and everyone could experience the effects of the interactions of the variables while the STELLA software handled the higher mathematics. Appealing to multiple intelligences, the rocket project got everyone actively involved in

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SYM BOWL EAST '99

An exhibition of student work in the field of system dynamics

Saturday, April 17, 1999

Worcester Polytechnic Institute, Worcester, MA

SyM Bowl East is

- a student exhibition of systems thinking and dynamic modeling
- an opportunity for students to see the modeling work of others
- a venue for novice students to display their work
- a celebration for students, families, and teachers

The SyM Bowl Concept

SyM Bowl began with the creativity and energy of Edward Gallaher, a research pharmacologist and SD in K-12 supporter, from Portland, Oregon. Teams of 2-4 students identify a problem (any area), identify reference behaviors, find experts and reference materials, build a model (simple to start with!), state assumptions, discuss parameter values, conduct sensitivity analyses, consider loop behaviors, and draw conclusions. A final report and poster session complete the process. A select group of projects is asked to present their work in a general session.

NEW!! This year we also encourage beginning modelers to submit a

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EDITORIAL. . .

As we go into the spring, New England is hosting its first SymBowl exhibition (and we are hoping that we do not get a fourth spring snowstorm on that day!) The evidence of spreading interest in system dynamics in education is afforded not only by the SymBowl now on both coasts, but also in the lively conversations occurring in both the K-12 listserve and the system dynamics listserve, both of which are represented in these pages.

Be sure to check out the new items on the List of Materials. There are some good additions which can be used in the classroom.

I hope that the learning in your classrooms matches the promise of the season.

Lees Stuntz (stuntzln@tiac.net)

RESOURCES

The following resource information was gleaned from several sources. We have not investigated accessability or accuracy of any of the information.

History Alive! offers auxiliary or stand-alone teaching materials integrating U.S. and world history with the arts, for middle and high school levels. Included are images, experimental group activities, reader response and writing activities, and prompts for culminating projects. (Teachers Curriculum Institute, Palo Alto, CA. 800-343-6828; www.teachtci.com)

Facing History and Ourselves offers materials and workshops studying racism, prejudice, and antisemitism, in the context of the history and lessons of the Holocaust and other examples of genocide, to help middle and high school students connect history and their own moral choices. (16 Hurd Road, Brookline, MA 02146-6919. Tel 617-232-1595; fax 617-232-0281; www.facing.org)

The American Social History Project produces curriculum materials for high school history, including *Freedom's Unfinished Revolution* and *Who Built America?* Many New York Essential Schools have participated in its programs linking the print, video and multimedia materials, and scholars of the Center for Media and Learning to classrooms. (99 Hudson Street, 3rd floor, New York, NY 10013; tel 212-966-4248 x201; fax 212-966-4589; http://spanky.osc.cuny.edu/~ashp/links.html)

The Library of Congress American Memory digital archive makes available primary materials of all kinds on the Web, including documents, photographs, music, drawings, pamphlets, oral history transcripts, and recorded speeches. Educators can search for curricular support in collections like the Afro-American Pamphlets (1818-1907), the Carl van Vechten photographs of the Harlem Renaissance era, documents from the Continental Congress, sound recordings of speeches by American leaders, and the history of women's suffrage. (www.loc.gov)

U.S. Historical Documents. From the Federalist Papers to Supreme Court decisions, teachers can search a large collection of historical documents, speeches, and addresses from the history of the United States at http://w3.one.net/~mweiler/ushda/ushda.htm. Another excellent source of (mostly U.S.) historical documents, from the Magna Carta and the Iroquois Constitution to the latest State of the Union address, can be found at the University of Oklahoma Law Center Web site. (http://www.law.ou.edu/hist/)

The New York Times Learning Network, with Bank Street College of Education, offers daily lesson plans for middle and high school that use news items to explore issues in history, current events and social studies, language arts, the arts, math and science, and technology. (www.nytimes.com/learning/index.html)

National Writing Project. A school-university network that brings teachers together to work on writing across the curriculum, examining successful practices and new developments from a variety of sources. Local and state chapters offer sustained professional development opportunities. (www-gse.berkeley.edu/Research/NWP/nwp.html)

Getty Educational Institute for Education in the Arts sponsors six Regional Institutes that help teachers of all subjects use the arts as a way of transforming whole schools. Programs help with curriculum development and arts instruction across the curriculum; model units, reproductions, materials, and online networking are available. (1200 Getty Center Drive, Suite 600, Los Angeles, CA 90049-1683. www.artsednet.getty.edu)

National Council of Teachers of English (NCTE) offers ongoing conversations from its Web site where teachers can trade ideas about teaching and assessment, class activities, home activities, composition, literature, whole language, and much more. (www.ncte.org/teach/)

Discovery Channel School. A wealth of television programming on subjects from history to science is organized here and linked to thoughtful lesson plans,

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constructing, testing and observing the rockets. From there, students moved into critical thinking using modeling.

The Teacher

Marti Lynes has taught physical science for 27 years, with 23 of those years at Algonquin Regional High School. Throughout her long career, she has always believed that high school science in general, and physics in particular, is not about memorizing a group of facts or mathematical problem-solving, "plug and chug." Instead, it should help students develop reasoning skills and gain an understanding of the relationships among the factors governing the behavior of systems. Teaching just sequential thinking is no longer good enough, she believes.

Although Marti has used computers as classroom tools for data-gathering and analysis in physics for over ten years, she has found that system dynamics computer modeling has brought even more power and excitement to the students' learning. It allows students to synthesize their knowledge and to see the interconnections among the parts of various systems. For Marti, it is important that her students develop this lifelong skill, not only for science, but also for other fields of endeavor and for the complex real-world problems they will face.

The Soda Bottle Water Rocket Unit

Student Objectives

- Students will understand the interdependent causal relationships governing the behavior of their soda bottle water rockets.
- Students will understand the basic principles of the physics of motion: Newton's laws, acceleration, velocity, thrust, net force, air resistance, kinetic and potential energy, gravity.
- Students will understand that acceleration is to velocity as velocity is to distance. It is a parallel structure made clear by system dynamics modeling. Building this parallel structure in STELLA is difficult for beginning modeling students. Surprisingly, it is also a stumbling block for some upper level math students who are facile with equations.
- Students will learn that acceleration at the top of the rocket's path does *not* equal zero. With the misconceptions students bring to this subject, many do not understand acceleration conceptually from just solving equations or being told; they need to learn it more experientially. Motion detectors and STELLA modeling help bridge this gap.
- Students will use creativity and independent thinking to solve a real problem. This is a design project, not a "cookbook" lab. There is *no* one "right" answer.
- Students will learn to conduct an iterative experiment. Through several trials, students will learn from the results of one attempt how to improve the rocket's performance in the next attempt. Mistakes are steps to the solution of the problem.
- Students will learn the basics of system dynamics modeling and build several simple introductory models. They will use this knowledge to build a simulation model of their soda bottle water rocket systems.
- Students will be able to troubleshoot and validate their models by comparing their graphs with the real world behavior they have observed. Is the behavior on the graph what it should be? Does it make sense physically? How does the performance of the model compare to the performance of their rockets?
- Students will generate "what-ifs" easily. They will use the models to further their experimenting by changing parameters within the model to see what happens to the rockets under varying conditions. They will determine what optimum values of the variables the model predicts and retest these on their actual rockets if time allows.

Designing and Launching the Rockets

Student Assignments: The Design Challenges

- **Challenge 1**: Build a soda bottle water rocket that goes the highest, but that does not make the astronaut dizzy by tumbling as it falls back down to earth. Your rocket *must* have fins and a nose cone. Use a 2-liter soda bottle and any other scrap materials from home. Enter all of your work into your journal. Keep all of your design sketches, predictions, and graphs. Good luck!
- **Challenge 2**: Second chance. Now that you have observed your first launch and those of other students, how would you improve your rocket to make it go higher or stay aloft longer? Try again.
- **Challenge 3**: Launch your rocket to land closest to a target placed down the field. Choose the amount of fuel (water) and pressure needed to hit the objective. Of course, if your rocket doesn't fly straight, you'll miss the target.
- **Challenge 4**: Keep your rocket aloft the longest, with maximum height and a soft landing. Design and build an enclosed parachute for your rocket that will deploy at an appropriate time and delay its descent.

Teacher Notes on the Challenges

The water rockets were the first of many Design Challenges for these physical science and physics students. They were given the rocket challenges one at a time, each building on the last, with *only* the limited instructions above.

Challenge 1: (Maximum height, minimum tumbling) An empty plain bottle is the lightest and goes the highest, but it tumbles. The fins and nose cone add stability and challenge. Students constructed fins out of paper and plastic us-

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ing glue and tape with varying success. They built nose cones out of posterboard, other bottles, and even a party hat. It is best not to give the students any construction hints beyond the initial assignment. Let the students find their own solutions, and they will come up with ideas you would never have even considered.

Exercise extreme caution while students are pumping up their rockets and launching them. The bottles themselves are designed to withstand pressures over 100 psi, but you must be sure that the launcher is securely anchored to the ground and that it is sturdy enough to withstand the pressure and repeated use. Be sure that everyone stands clear when the bottles are pressurized and as they gain speed after launch. During their descent, most rocket bottles are light and fall gently, but some student designs will be heavy and pointed straight down and must not be allowed to strike anyone. Do not leave students unattended with this project.

Students conducted these experiments on the baseball field where luckily there was a water hose nearby. With a bicycle pump, they pumped the bottles to a constant pressure of 70 psi (using gauges that were not very reliable.) The assignment was to see whose rocket would go the highest, but when it became too close to judge, time aloft was measured instead. This changed the challenge slightly but worked better with this group. (Many rockets climbed at least 30 meters in less than 2 seconds.)

These launches were scheduled during long class blocks so that each student could try at least two launches each day. Some students could not launch again on the first day because their fins or nose cones had fallen off, but the rest decided to try varying the initial amount of water in their rockets.

Encourage all students to observe other students' rockets so that they can learn from one another's successes and mistakes.

Challenge 2: (Second try) Students got a chance to try again with improved rocket designs and varying water amounts. They found ways to build rockets that held together and some students discovered what seemed to be the optimum initial amount of water.

Videotape these launches to gather data for building computer models. In order to capture the whole trajectory of the rocket without moving the camera, stand back 200 to 300 feet from the launch pad. Plant a 2-meter stick near the pad as a measurement reference. Later, students can attach sheets of acetate to a television screen and mark the location of their rocket with a dot as they advance the video one frame at a time. These graphs measure only the height; they do not account for distortions due to wind or parallax.

All students, freshmen and seniors, in standard and honors classes, conducted the first two challenges. Honors and standard seniors and honors freshmen went on to complete the next two challenges.

Challenge 3: (Target launches) Place a target partway down the field and ask students to aim for it. The launcher was mounted on a hinged piece of sturdy plywood so that students could vary the angle of the launch. Although this was fun, not many rockets landed very close to the target. In fact, they went everywhere! It would take more than one class period for students to refine their attempts. If you are limited for time, leave this challenge out; it is not included in the later modeling assignments.

Challenge 4: (Maximum time aloft, soft landing. Parachutes.) Again without specific instructions, students used their ingenuity to build parachutes that would deploy and keep their rockets aloft. Most students placed the parachutes inside their nosecones. One problem they encountered was that nosecones were forced on so tightly during launch that they would not come off as planned. Let students make this discovery on their own; leave the problem entirely to them and students will find successful solutions. Videotape these launches and keep the data for later when the students will add air resistance to their system dynamics models.

Honors and standard seniors and honors freshmen completed Challenge 4. In some cases, the freshmen were more successful than the seniors, with one student setting the record for a time aloft of 17 seconds. Later, in interscholastic competition, this record was doubled by another freshman whose rocket disappeared over a building!

Student Assessment

All students were required to write a report on the design challenges. They also had to submit all design sketches, journals, graphs and a self-evaluation of their work. A sample evaluation sheet follows. Because this was the first design project of the year, the guiding questions were very specific leading students to think carefully about what they had learned. Later in the year, after one or two design projects per term, students knew what belonged in a report. Seniors wrote about all four challenges. Standard freshmen omitted the last two.

Introduction to System Dynamics Modeling for Students

Before students can build a system dynamics model of their soda bottle water rockets, they need a basic understanding of the principles of system dynamics and a familiarity with STELLA software. Freshmen spent about 3 class periods on the introductory exercises in *Getting Started: Five Lesson Plans to Help Teachers Introduce System Dynamics to their Students*, by Cathy Greene Curry. Seniors spent one class period.

Building Simple Models

After completing the five "Getting Started" lessons, students are ready

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Systems Thinking in School Administration: Part 1

Matt Hiefield

Over the past several years, I have seen how systems thinking can be a great tool for the classroom teacher. As a teacher, I often marvel as students start to see the interdependency of systems, pose high level questions, and question assumptions.

While sitting in meetings and listening to others, though, I also started to realize that some of our district's best administrators were thoughtful systems thinkers (and the opposite being true as well . . . some of our least effective administrators are not systems thinkers).

As a result, I decided to schedule an interview with Rick Miller, principal of Sunset High School in the Beaverton School District, a suburban district west of Portland, Oregon. The following discussion is based on my interview with him. We examined several different aspects, some of which will probably appear in a future article, but the central focus was around the areas that are critical for systems thinking in the realm of school administration.

Matt Hiefield (interviewer): What areas are critical for systems thinking for the administration of a school?

Rick Miller (principal): Administrators have several audiences to consider in the decision making process. First of all, decisions affect students at different grade levels in different ways. Moreover, the parents of 9th graders have different expectations and needs than the parents of 12th graders. Another audience, of course, is the staff of the school. Within a staff, you might have departments with different philosophies which can be in direct conflict. Finally, the greater community is an important audience in the decision making process. With all of these audiences, a seemingly simple decision can become very complex, with multiple factors influencing one another.

MH: What about a specific example of this type of complexity?

RM: Well, there are many examples, but attendance is a good place to start. As a school and educational community, we all need to ask ourselves why students skip and/or drop out of school. As it turns out, there are many interrelated factors that can vary from student to student. Is it factors outside school, the school environment itself, the type of schedule and course offerings, class size, class composition, grading behaviors, or another factor that is the most important? How do these factors affect one another? Does working on one factor have any unintended consequences? In looking at attendance and student behavior, it is important to avoid overly simplistic remedies without trying to examine the whole system.

MH: In planning for each school year, staffing is always a big issue. What are some of the systemic factors that you need to consider when forming a staff?

RM: In hiring teachers, there are certainly many factors that are sometimes in conflict. One of the biggest considerations is teacher certification. This seems straight forward, but it isn't always necessarily the case. For example, some teachers are certified in several areas but only want to teach in one specific area. By asking to teach only a certain class, this limits the options for teachers with single certifications. Other teachers might want to teach a specific class but haven't been officially certified in that discipline. In addition, Teachers Standards and Practice Commission in Oregon doesn't always allow out of state certifications to transfer. Sometimes, there might be a push from the community to teach a certain class, but we might not have someone qualified to teach it. This creates a dilemma between looking for a specialist in that area to bring to our school and possibly having to have another teacher transfer somewhere else. Sometimes it isn't a win/win situation.

MH: How does the number of students at school fit in with this?

RM: The number of students directly affects the number of teachers we hire, but how the students sign up for classes directs class offerings. Once the initial numbers come in, some interesting philosophical discussions have to take place. For example, are we willing to allow some classes to be bigger than others so that we can offer a class that has only 18 students in it? Moreover, do we think that 9th grade classes should be smaller in order to facilitate the transitions into high school? Should high level classes be smaller since they might require more correcting of papers outside of school? In essence, every course offering decision affects the whole system in some way, and these decisions are often based not only on the numbers, but on educational philosophy. In the end, it boils down to the following key factors:

*Scheduling the 9300 requests for classes (1550 students multiplied by 6 classes).

*Fitting all of these classes into our current six period day.

*Trying to schedule all of these classes into a limited number of rooms.

*Working to give each instructor their own room (we have some teachers who teach in two or three different rooms throughout the day).

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In considering staffing, class size, and course offering issues, it became clear that many forces in the system were affecting other aspects, and some aspects were in direct conflict with one another. In discussing educational philosophy, it became clear that every school makes

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Transferability: a summary of the question from the K-12 listserve

Tim Joy, December 21, 1998 - the Winter Solstice

THE QUESTION

Transferability—the capacity a student has to use knowledge from one area in a completely new area—recently surfaced as a legitimate assessment of systems' veracity and power. How, then, do we foster transferability? Second, how do we measure it?

"Don't you get it, George? A man's life affects so many others. When he's gone, he leaves quite a hole."
Clarence, George Bailey's guardian angel from "It's A Wonderful Life"

Last month, I inadvertently omitted a colleague's comments. Serendipitously, Alan Ticotsky's comment on discerning stock from flow speaks to the heart of this most recent conversation about transfer: "With young students, we talk about simulate, count and then graph things that accumulate and decline, e.g., water in a pond, trees in a forest, friends in a school." How often have we ever asked our students to consider their friends as similar to anything else, let alone water in a pond? In that most basic teaching function, Alan reminds us of what the good teacher does—give the student a personal starting point upon which to build new ideas.

Many of us have stories of break-through moments, wherein we witness a student's light vanquish the darkness. One such story captured the essence of this recent conversation: Tracy Benson's story of Michael, an 8th grader who learned the power of knowing a system. On this day of least light, it is good for us to remember that our students bear extraordinary gifts.

This month's question was divided in two parts, but quickly diverged. We found this topic to be full of questions and directions, but only a few certainties. It holds for us the likely kernels of proof we are searching for in our endeavor to demonstrate the veracity and ubiquity of system dynamics

FOSTERING TRANSFERABILITY

Use models that clearly need input from other fields. One of the few things that we can be certain of regarding our current educational paradigm—wherein students learn material in discrete bits, sequentially and separately—is that students have little intellectual initiative; if we don't tell them what to do, many are uncertain about how to proceed. To the extent that SD problems are cross-disciplinary, students will be engaged. Further, to the extent they have success in this, they gather confidence. This seems also to be the case as well for teachers, since this is where all the interesting problems are.

Do lots of news items, use the newspaper in any way related to your subject.

Teach to the big picture. Always consider the context of the prevailing specific subject, but keep the larger picture in view.

When introducing SD, the greater the variety of real world examples, the better; this encourages students to apply the concept of systems to many situations.

One of the purposes of teaching SD in the classroom is precisely to foster transferability. Therefore, teach a competency (e.g., translate a narrative description, such as Lord of the Flies, into a BOT graph) in one context and then "test" for it in another.

Students may not even be aware of the idea of transfer, so this needs to be presented to them. In various insidious ways, we need to engender archetypal thinking. Many mentioned that high schools have so compartmentalized education that subjects other than the one being taught are considered "other" and, therefore, unimportant, irrelevant. And so our children are mistaught.

Make a direct request for transferability. This is intuitively obvious as I type this, but I realize that only people on this list mention it at all; it's a rarity inside most schools. In fact, most people who contributed this month made at least an oblique mention of this idea.

Pure George Richardson: To get transfer of system dynamics insights from one context to another, we'd have to help students expose the "identical elements" [of their problems]. We could design exercises that draw students from the particulars of a particular model or map to the 'crucial structure' of the model or map, and then from there to an abstract structure of a map…This is the process that produced the [systems] "archetypes."

We need to teach directly to transfer: some kind of explicit abstracting exercises that move from particulars to general and back to other particulars.

CAREFUL … we ought also to ask students to consider when an idea or model is not like others. Though we wish students to see across boundaries, they must do so with a critical eye.

Put another way, to the extent that SD is used for only a single lesson with no reference or connection to another idea or field, then we may be misteaching. Does this mean, every systems problem or model construction ought to include an archetypal, generic, or transfer component?

We should use storytelling more. Niall Palfreyman reminds us that metaphor "presuppose[s] an ability to transfer knowledge from one domain into another." Others continued on this metaphor theme, noting that this was a rich field for us. There is a very strong correlation between transfer as we are discussing it and metaphor as we know it from literature. As an English teacher, I wonder how much metaphor shows up in science and/or mathematics courses.

Aristotle tells us that metaphor is the surest sign of genius. Metaphor "practices what it preaches." It is a perfect model of the transfer of knowledge from one context to another.

The metaphoric mind has certain qualities: an ability to see patterns, templates, similarities.

We tend to learn through modeling others.

Generalization is a naturally occurring phenomenon. By varying the features of the situation in which we teach (using both verbal dialogue and written language, providing learning activities both inside the classroom and out, asking students to work alone and in collaboration with others, asking students to solve one kind of problem and to solve a very different kind of problem) we can increase the likelihood of generalization. One of this century's great generalists, Joseph Campbell (Public Television's "Power of Myth"), said that humanity tells but one story—the quest story.

Debra Lyneis also reminded us of Jay Forrester's comments last month: 1) All activity everywhere occurs within and is controlled by feedback loops; 2) Feedback loops (and therefore all systems) consist of two, and only two, concepts—levels and rates. As she says, this is the "essence" of transferability. She suggests we ought to study SD applications that are enitirely out of our field in order to overcome our propensity to compartmentalize.

MEASURING TRANSFERABILITY

We need help in this area. There is much we can learn from other educational movements and their methods of measure. And yet, maybe our stories give us a more direct line to parents and politicians: not statistics, not educational abstracts, not psychological studies, just a myriad of stories akin to Michael's.

Not sure how we can "measure transferability" without changing the very structure of schools: probable changes include less content-based testing, which as many of us discussed last June in New Hampshire, tends to pull curricula in a particular direction. Gordon Kubanek (Ottawa) goes on to suggest that questions ought to "integrate.… [that we should] require explicit connections between what a student learned in history or English with… chemistry." In short, there is little in the current system to foster this skill. The whole system is utterly compartmentalized. He mentions that teachers "would have to talk with the other subject teachers and see what they have been studying." A switch from departmental to grade level meetings may well accommodate this, as it does at least put the various teachers in the same room.

Suppose a student learns about transfer through BOT graphs through a variety of incidents in the same novel, but is then tested by a larger step, a narrative from a different novel. This may provide a means to actually "measure" the transferability. John Gunkler's comments on this idea were quite interesting (see his posting of 11/16/98) and for those on this list with interest in assessment, he gives a good thumbnail sketch of how one might go about this.

Many mentioned that we ought to be collecting anecdotal information at every turn: Teresa Hazel mentioned that we ought to record conversations among student teams as they solve problems.

What should we be expecting to see from students? Would students trained in, or who are using, SD be more apt to see a system and propose a systemic solution than address an "acute problem" that has a solution?

MICHAEL TORE THE ROTE ASUNDER

After waiting a month through our conversing, Tracy Benson shared a poignant story of young boy named Michael (see 12/9/98) who was "unhappy with his math teacher." Since he had studied a particular systems archetype in history class, namely, the "escalation archetype," Michael was able to identify his troubles as just that—escalation—and he was able to determine a number of conditions that existed in his relationship with the teacher. Having identified these conditions, they put together a plan to break the cycle. Even the teacher and parent participated in the discussion using the systems archetype. It was an extraordinary story of how a systems approach cuts across the traditional educational grain.

She concludes: "The benefits of this transfer may be too far-reaching to be worthy of traditional measurement; the power is in the story."

Tracy's story capsulizes our transferability discussion. It is quite likely many of us have similar stories, and, clearly, we should be collecting them. Maybe we should call Michael's discovery a "Forrester moment," what George Richardson declared as the thinking we want to engender, when rather than merely seeing the temporal, we see the template.

SOME HOLIDAY READING

Lessons From History, Will and Ariel Durant; *In The Mind's Eye*, Thomas West; *The Unschooled Mind*, Howard Gardner; *Hero With A Thousand Faces*, Joseph Campbell; *Dune*, Frank Herbert; *Thinking In Time*, Richard Neustadt; *Urban Dynamics*, Jay Forrester; *Mind As Nature*, Gregory Bateson; *Parabola*, a quarterly publication of Shambala devoted to one archetype an issue.

RESOURCES

Road Maps; Pegasus Books and Publications; Creative Learning Exchange; Our students

QUOTABLES

"Transferability is not something a teacher tacks on to a lesson, but more

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fundamentally has to do with how the learning/teaching is done." John Gunkler

"Never underestimate man's ability to compartmentalize." Lees Stuntz

"If you want transfer you have to teach for transfer." Janice Kowalczyk

"To evaluate whether greater learning occurs by a particular teaching/learning approach, we need to have the freedom and flexibility to test in the same way that the students learned." Teresa Hazel

"We have to invent the experiences that help kids… uncover transferable insights themselves." George Richardson

"It's just like one of those loopy things." Michael, on seeing a system's archetype in the heat of the moment

"Experts and specialists lead you quickly into chaos… The expert looks backward; he looks into the narrow standards of his own specialty. The generalist looks outward; he looks for living principles, knowing full well that such principles change, that they develop. It is to the characteristics of change itself that the mentat-generalist must look." The Mentat Handbook, Children of Dune, p 221

"Models are analogues."
John Gunkler

"Recognizing generic structures may well be a key upon which to build transferability skills." Mike Slootmaker

"To teach transferability to the kids, we need to sharpen that skill ourselves, if as Forrester says, it's everywhere. We can do that if we continue to treat ourselves as a community of learners" Debra Lyneis

"I have been a student of system dynamics for over 40 years." Jay Forrester, via Debra Lyneis

"Transferability of structure and behavior should create a bridge between science and the humanities. Feedback-loop structures are common to both. An understanding of systems creates a common language. Science, economics, and human endeavor rest on the same kinds of dynamics structures." Jay Forrester, June 28, 1994, Keynote Address

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The K-12 listserve is a monitored list for discussion of system dynamics in K-12 education. For past discussions see: http://sysdyn.mit.edu/k-12sd-email-list/archive/home.html Send contributions and all requests to subscribe and unsubscribe to: k-12sd@sysdyn.mit.edu

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Interview with Matt Hiefield *continued from page 5*

assumptions on what is best for students, staff, and the community. This often involves several different types of feedback loops. For example, good programs can attract students and/or motivate students to stay in school, and success can increase enrollment in future years. Success often brings parental support, and parental support fosters more success. As classes grow in one area, this means that other programs can be impacted in a negative way. Changing class sign ups affects staffing allocation, and this in turn can affect class size. As needs fluctuate in the school, certification issues become increasingly important as well.

In sum, effective administrators are systems thinkers by nature. They have to be to foster success in such a complex organization. In grappling with these issues, educational assumptions and values become increasingly important, and being able to articulate and test assumptions is essential in building a successful school.

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BOTTLE ROCKETS

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to build a series of models leading up to a model of their soda bottle water rockets. All students worked on these introductory models, seniors and freshmen, in honors and standard classes. Students worked alone or in pairs at the computer. Let the students figure out all of these simple models on their own.

Bank Account Model

Building on the last exercise of the "Getting Started: Five Lesson Plans," ask students to model their own savings accounts. First ask them to explore various interest rates and compounding time intervals. Then ask them to assume a constant interest rate and to estimate how much money they intend to deposit and withdraw each month. Final Question: Will they have enough money to buy a car by the time they graduate?

Bathtub Models

Building on the bathtub analogy in "Getting Started: Five Lesson Plans," ask students to model a bathtub filling and draining with various starting conditions and rates. For all of the models, the students did hands-on experiments at the sink to estimate water flow rates. You can fill paper cups with drain holes poked in them, but large institutional-size tin cans from the cafeteria work better because students can more easily see that the drain rate varies with the depth of the water in the can.

Students observed the water flow, but they did not have to measure it. The goal of this exercise is for students to grasp the concept of feedback. Doing it quantitatively at this point would take too long and it is not essential to the understanding of feedback. For these introductory models, students should focus on the *shapes* of the curves rather than on matching the data precisely.

Bumblebee Model and Baseball Model

Students use the concepts of starting position and rates in kinematics

SODA BOTTLE WATER ROCKETS, *continued from page 8*

to build a model of velocity and position. Then, using what they have learned in kinematics, students build a model of a baseball being thrown straight up into the air by adding acceleration to the bumblebee model and giving the baseball an initial velocity with which it leaves the hand.

With this model, students are introduced to the concept that acceleration is to velocity as velocity is to displacement. This may be difficult for many students to grasp at first, but the idea is central to a conceptual understanding of the physics of motion. The structure will become the core of the rocket models. The relationship becomes clearer as students build and manipulate computer models of their real-world rocket experiments.

Building the Rocket Models

Now students are ready to build STELLA models of their soda bottle water rockets. Students built the first basic rocket model right after they had completed the previous simple models. All students, freshmen and seniors, got this far. Even students who were just beginning algebra could successfully model thrust without solving any difficult equations.

Flow diagrams, equations, and explanations for the rocket models come next. The STELLA models themselves accompany this paper. They are in STELLA Version 5.0, unlocked and ready to use. Do not just give the models to students, however. Let them build the models themselves. The students may struggle at first, but with system dynamics modeling, the learning is in the doing. They will deepen their understanding of physics

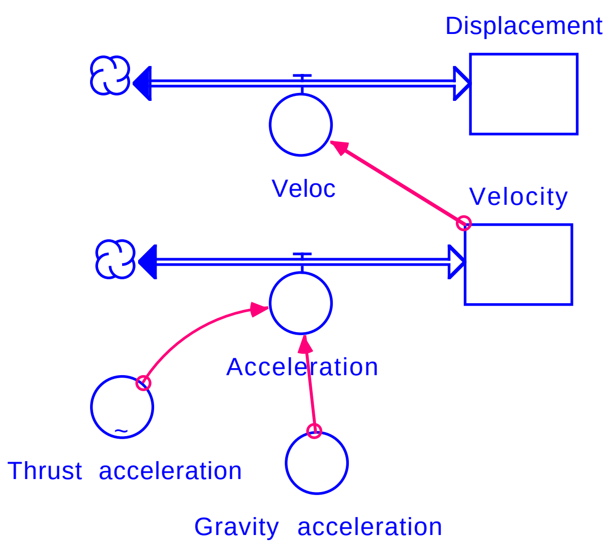
if you let them examine and specify the relationships on their own, as you circulate among them offering guidance.

Modeling Stage 1: Basic Rocket Model with Thrust

Ask students to use what they have learned in the baseball model and extend it to build a model of a rocket including acceleration due to the thrust of the ejected water. Will the acceleration be constant, increase as the water leaves, or decrease? They can enter a constant “Acceleration due to thrust” or use a graphical input to show how they think thrust affects the acceleration.

Modeling Stage 2: Rocket Model with Thrust and Air Resistance (Constant Mass)

Ask students to adjust the model to mimic the behavior of the soda bottle water rockets in their experiments. Use the videotapes of their rocket launches to provide real world data for how the models should behave. It will be easy to see that some rockets are more affected by air resistance by noting the larger differences in time coming down compared to time rising. Other rockets are affected very little.



Stage 1 Model

The Stage 2 modeling assignment becomes a real challenge for students who are new to the idea of vectors. Getting the signs right takes some serious consideration. The acceleration due to the thrust is positive, the acceleration due to gravity is negative, but the acceleration due to air resistance changes sign, since it always opposes the motion. So when the velocity is positive (up) the air resistance vector is negative (down) and when the velocity is negative (down) the air resistance vector is positive (up).

There are other challenges. Students must build a feedback mechanism into the model because air resistance (drag) is dependent on how fast the rocket is traveling. Students must also define the shape of the curve in the graphic function for “Acceleration due to thrust.” Finally, they must experiment with air resistance and the constant “k_2” (the drag coefficient) to examine the effect of changing the cross-sectional area of the rocket. (See Appendix B for a complete discussion of air resistance values.)

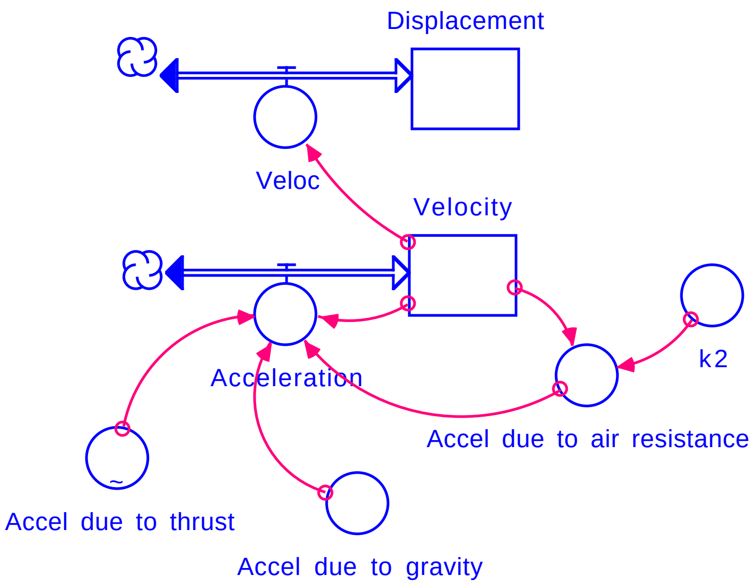
The students’ understanding deepens as they work at building the model, but this process can be very frustrating for them. They may even moan a lot at this stage! Encourage them to keep at it, however. They are all delighted when they finally get their models to work.

Once this model is complete, lots of “what-ifs” can be explored, even the effect of a parachute suddenly opening.

Encourage students to use the model to extend their experiment by trying other “what-ifs.” What if the rocket were launched on the moon where $k_2 = 0$ and gravity is less? What if a parachute deployed? What if the rocket had an umbrella for a nose cone? Ask students to make their own predictions about how the flight would change under different circumstances and compare their predictions to the model output.

***Bottle Rockets** continued on page 10*

SODA BOTTLE WATER ROCKETS, *continued from page 9*



Stage 2 Model

Resources, *continued from page 2*

downloadable primary source readings, and more. (http://school.discovery.com/lessonplans/subjects/k-12.html)

PBS Teacher Source has comparable offerings from public television's storehouse. (http://www.pbs.org/teachersource)

Through the Glass Wall. Good math-based games can be intellectually demanding and entertaining, but they're not easy to find. With descriptions of over 50 commercially available games, this Web site shows teachers and parents how to find equitable mathematical computer games. The site also features game reviews, sample dialogues from children playing selected games, and print and Web resources focused on gender equity and computer use. (www.terc.edu/mathequity/gw/html/gwhome.html)

Mathematics of Change. This site is home to five Technology in Education Resource Center (TERC) projects making calculus an accessible and relevant area of mathematics. It includes information on how technology tools such as computers, graphing calculators, and motion detectors contribute to students' understanding of real-world application of calculus. The site features an extensive bibliography, information on school partnerships, and the history of TERC's research on the teaching and learning of the mathematics of change. (www.terc.edu/mathofchange/MoC/index.html)

Consortium for the Advancement of Social and Emotional Learning (CASEL). The CASEL Web site lists descriptions, target grade levels, and contact information for 23 social and emotional learning programs. Beginning this year, CASEL will also include its evaluations of some existing SEL programs on the site. (http://www.cfapress.org/casel/casel.html)

Problem-Based Learning Network (PBL Net) encourages its members and interested educators, parents, students, and community members to post questions and share ideas about problem-based learning through a listserve and an electronic interactive forum on the Association for Supervision and Curriculum Development (ASCD) Web site at http://www.ascd.org. Other PBL Net services include a newsletter and a meeting at ASCD's Annual Conference. For more information about PBL Net, contact Linda Torp, Strategic Coordinator for PBL Initiatives, Illinois Mathematics and Science Academy, 1500 W. Sullivan Road, Aurora. IL 60506 Tel 630-907-5956 E-mail: <ltorp@imsa.edu>.

Modeling Stage 3: Forces on a Water Rocket

Rebuilding the model in terms of forces instead of accelerations will help students clarify the relationship between these two concepts. (This interim model will also be used to build the next model with changing water mass and changing pressure.)

Modeling Stage 4: Changing Water Mass

Good Questions

So far, the Stage 1, 2, and 3 models begin to explain the behavior of the soda bottle rockets, but they also give rise to many good questions. Some things are obviously missing in these models. A further step would be to consider other variables, build them into the model, and then determine which of these have a significant effect and which may be of small account, such as:

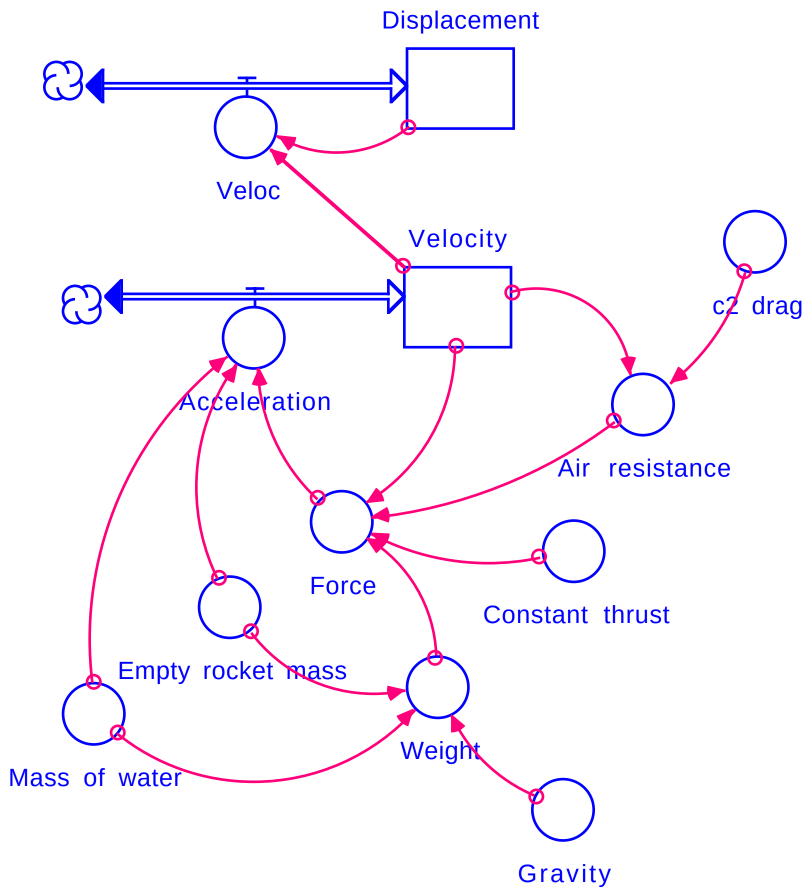
a) Should the thrust increase, decrease, or remain constant during the flight? Rather than just guessing, can we use the gas laws to find out?
b) Can we assume that the expansion of the gas is adiabatic? In other words, which gas laws should we use?
c) Can we assume that the force (thrust) is equal to the pressure times the area of the surface of the water inside the bottle, or does thrust depend on the area of the nozzle opening? Can we ignore the effects of friction on the water as it travels through the neck of the bottle in calculating the thrust?

d) The thrust may indeed be inversely proportional to the volume of air still in the bottle, but we must notice that the mass of the object on which the thrust acts is continually decreasing. Is that change linear? How can we take into account this rather large change in mass as the water is expelled from the rocket?
e) Does the model behave reasonably at the boundary conditions, i.e., full of water (no air pressure), or empty of water? And what if not all of the water has come out when the pressure inside the bottle reaches atmospheric pressure?
f) If the water is all gone, but the pressure is still above atmospheric pressure what happens? Does the remaining gas expand adiabatically? What effect does this expansion have on the thrust? Quite a few times we observed that a cloud had formed in the bottle. Does that mean a cooling effect occurred? How much? Does that affect the total thrust in a significant way?
g) What about momentum?

These are all good questions and students gain a deeper understanding of the rocket system by discussing these and the many other good questions that spontaneously arise during the modeling process. The students may not yet be able to build a model to answer all of their questions, but the deeper probing itself is very engaging and valuable.

Modeling Changing Water Mass

The Stage 4 model investigates the effect of the changing water mass on the rocket. This modeling assignment has not been tried with students, but seems to follow naturally as we look at the complex system we are trying to understand. Building on the previous model, the Stage 4 model needs another stock for the water in the bottle and a flow to describe how it drains. Varying pressure and mass all come into play. Students have to think about all of the relationships that govern the behavior of an increasingly complex system.



Stage 3 Model

A Different Approach to Physics

System dynamics modeling offers students a different approach to physics. It helps them gain a deeper operational understanding of how things actually work. Students don't just learn about the parts of a system. They learn about how all of those parts are interconnected and how all of the relationships play out over time together. They learn about feedback and change. It is not enough to say that pressure affects the acceleration of the rocket, for example. What exactly does the pressure do? How does it affect the rate water is expelled from the bottle? How does it influence thrust? What else changes as the pressure drops? You're not asking kids to recite equations. You're asking them to think about what they have observed and to use what they know about physics to understand the change. You're also giving them a visual tool to understand the relationships causing the change.

The "Soda-Bottle Water Rockets" article by Kagan, Buchholtz, and Klein in *The Physics Teacher,* described earlier, shows a contrast. The authors conduct very exciting experiments, but the explanations soon become very complicated, using advanced math way beyond the grasp of most high schoolers. It's difficult for students to just look at the complex equations and understand what is happening. Also, the final equation only describes conditions at one point in time. You can feed this into a spreadsheet and that will show the rocket's path, but you still don't get a picture of how all the parts of the system are interconnected and changing in rela-

***Bottle Rockets** continued on page 2*

SODA BOTTLE WATER ROCKETS, *continued from page 11*

tionship to one another. With system dynamics, you get a visual representation of the causal relationships, and you see the dynamics. System dynamics modeling helps make the physics understanding deeper and more accessible to students.

Student Feedback

One former student wrote to Mrs. Lynes:

"When I took my first physics course at Stanford, I found myself up against many students from private and magnet schools who had taken two years of calculus-based physics, the AP exam, and had covered more topics. Yet I found most did not possess as advanced a physics intuition as most Algonquin HS honors students do by the end of the year. While their breadth surpassed mine, they lacked enough real understanding of concepts to be able to use their knowledge on difficult exams. Your class helped me to develop not only a knowledge of physics, but an understanding and indeed an intuition. I didn't realize the full value of this until the first exam in mechanics when I joined 3 other students in a 300+ class in acing the exam. …I have been able to get straight A's so far in the physics core."

Two years later, this same student wrote to Mrs. Lynes from Germany:

"After studying at Stanford's program in Berlin, I now have a six month internship developing a computer model of an airbag for Volkswagon. Trying to create a realistic computer model of an airbag reminds me of working on STELLA models of water rockets. A bit more complex, but similar principles and challenges. Another fine example of where your class was years ahead of many other high school classes."

Your Feedback

We welcome your suggestions or concerns about this unit. If you try these lessons, we'd especially like to hear about successes and pitfalls with students, and about other new lessons that you may have developed. Please send your comments to us through the Creative Learning Exchange. Thanks.

Materials and Resources

For More Information:

- "Soda Bottle Rockets," by David Kagan, Louis Buchholtz, and Lynda Klein, in *The Physics Teacher,* Vol. 33, 150-157, (1995). This excellent article carefully explains how to build and launch 2-liter soda bottle rockets and provides all of the supporting theory and equations. Differing from Marti's experiment, the authors did not use fins or nose cones, and they used high-speed photography and Smart Pulleys for measurement. They also asked students to build spreadsheet models instead of system dynamics models.

- "Water Rockets I, Grades 3-12 (introductory)," "Water Rockets II, Grades 6-12 (intermediate)," and "Water Rockets III, Grades 10-College (advanced)," by Dr. Ron Bonstetter and Jake Winemiller. Insights Visual Productions, Inc., P.O. Box 230644, Encinitas, CA 92023; (619) 924-0528. These three videos and the accompanying teacher's manual explain how to build and launch 2-liter soda bottle rockets. They explain the science and give lesson plans appropriate to each grade level.

For Building the Rockets:

- Students construct their rockets at home using 2-liter soda bottles and commonly available materials such as paper, poster board, plastic scraps, tape and glue.
- The launchers can either be purchased or constructed from easily obtained materials.
- Launchers can be purchased from any scientific supply company. One from Arbor Scientific (approximately $20.00) was used for these experiments. It was mounted to a hinged board to change the angle for target launches. PITSCO also offers a very nice launcher for about $175.00.
- Construction instructions:

  There are very detailed instructions on how to build a launcher using PVC pipe, 2x4s, a valve from an old inner tube, and other hardware store supplies, in "Soda Bottle Water Rockets," by D. Kagan, L Buchholtz, and L. Klein, above. There are also plans for a homemade launcher made out of PVC pipe, hosing and an electrical box in the "Water Rockets" videos by Insights Visual Productions, also cited above.

For Building the Models:

- Modeling software: STELLA, High Performance Systems, 45 Lyme Rd., Hanover, NH 03775. (603)-643-9636. This software is available for the Mac or for Windows. The models in this unit are in STELLA 5.0. (STELLA 2.2 easily supports construction of Stage 1, 2, and 3 rocket models.)
- Computers: Students can work alone or in teams on computers. In this case, half of the students worked alone and half worked in pairs.

Note: The original document was severely abridged in order to fit in this newsletter. The above article is merely a taste of the richness of this particular curriculum. We urge you to access the entire document and the four models from us or the Web site http://sysdyn.mit.edu/cle/ The 8-character title is BOTTLEML.

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Purposes of Archetypes

Dr. David C. Lane, London School of Economics

The following is reprinted with the permission of the author from the System Dynamics listserve. I found it interesting and thought-provoking.

Responding to Jaideep Mukherjee's query about finding more archetypes, I would say two things:

On Accumulation of Archetypes

As has been noted by no less than George Richardson (Richardson, 1996), our field has been less than perfect in accumulating knowledge on a number of fronts, archetypes and other generic structures being but one example. However, for a range of lists and examples—in addition to The Fifth Discipline—see (Meadows, 1982; Paich, 1985; Senge, Roberts, Ross, Smith and Kliener, 1994; Lane and Smart, 1996). For comment on how to go about hunting and selecting archetypes onto the list, see (Lane and Smart, 1996) and (Lane, 1998a).

There is also an intriguing topological generation line of attack mentioned in that last paper, and something like it has been achieved in (Corben, 1995). Finally, Khalid Saeed and I have chatted briefly about starting with modes of behavior and working back, though this sounds as though it might be drifting over into the 'Abstracted Microstructures' area (see below). Something like this is contained in (Senge, et al., 1994) but a more comprehensive search would be possible.

On The Purpose of Archetypes

Archetypes are an odd animal for our field to have generated. We are dedicated to the rigor of simulation as the only way to deduce the behaviour of a formal model, yet archetypes ask us to infer behaviour. We know that this is very, very difficult. Archetypes are best thought of as one of a troika of Generic Structures: Canonical Situation Models (general models), Abstracted Micro-structures (pieces of structure which produce a characteristic mode of behaviour), and Counter-intuitive System Archetypes (simple CLDs offering an explanation for an odd system response and an outline reason for trying a different policy lever). The justification for this split is in (Lane and Smart, 1996).

The interesting question is then whether Archetypes are merely system dynamics models and insights for 'civilians' or something rather deeper. A critique of the validity of Archetypes may be found in (Lane, 1998a). What this tries to show is that not all system dynamics insights are expressible as Archetypes and that Archetypes have a range of other difficulties too. So from a traditional perspective they look like pretty thin gruel. However, the radical alternative is to say that Archetypes are 'ideal types,' in the sense of Max Weber. This means that they are devices which seek to provoke the user into thinking in certain loose categories and comparing real world phenomena with the ideal type in order to generate explanatory insights. This view pushes Archetypes into being a tool for a more interpretive form of system dynamics. I have discussed—both on paper (Lane, 1998b) and with Peter himself—whether this fits Senge's ideas. I have also explored what it would mean for system dynamics to adopt this stance (Lane and Oliva, 1998).

The point about this rather theoretical debate is that unless we have a clear understanding of *what it is* we are trying to accumulate, then accumulation is going to be pretty tricky, because appropriate criteria are lacking. I think that that has happened with Generic Structures, and (Lane and Smart, 1996) tried to tackle that lack. The same problem may now be transferred to Archetypes. So: think before you grab!

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The Creative Learning Exchange thanks Dr. Lane and the London School of Economics for their kind permission to reprint this article in the newsletter.

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SyM Bowl '99 continued from page 1

poster session (only) for evaluation and commendation in a non-competitive arena. These students will have an opportunity to see others students work, get feedback, and improve their abilities for future SyM Bowl events!

Wayne Wakeland, Ph.D., Systems Science Dept., Portland State University, and Edward Gallaher have evolved excellent judging criteria over the past 3 years of SyM Bowl competition.

The Event Itself

- A paper (50%) is required (in advance). The writing, formulation of the problem, etc. provides 25% of the score; modeling expertise provides 25% of the score.
- Poster presentation (25%). On the day of the event, teams present their models in an open-house forum (9:00-11:30). Each team has a table and a computer, and they develop a background poster to illustrate their project. This session is open to the public, and students are encouraged to circulate and observe other projects.
- Formal presentation (25%): Studies are selected to present a 15-minute talk to the entire audience in an auditorium.

After a 30-min break, we conclude with an awards ceremony for all participants. Award amounts will be determined based on the level of financial support obtained in fundraising.

For applications and arrangements contact:

Will Costello
Waters Center for System Dynamics
Trinity College of Vermont
Burlington, Vermont 05491
will@cvu.cssd.k12.vt.us

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NEW MATERIALS NOW AVAILABLE FROM THE CLE

The following new documents are now available from us or the Web site <http://sysdyn.mit.edu/cle/>

SYSTEMS EDUCATION

GETTINSC ***Getting Started with System Thinking in the Primary Grades.*** Sharon Coffin
From Maumee Valley Country Day School, presented at the 1998 Systems Thinking and Dynamic Modeling Conference in Durham, NH. Sharon Coffin's account of her start in teaching systems thinking and some curricula she developed to teach the concepts to the primary grades. [Systems Education, Causal Loops, Behavior over Time Graphs, Cross Curricular, English, Math, Science, Elementary School, Middle School] ($1.00)

INTEGRSS ***Integrating Systems Thinking and System Dynamics into an Elementary Classroom.*** Scott Suter and Jennifer Hirsch
From Catalina Foothills School District, presented at the 1998 Systems Thinking and Dynamic Modeling Conference in Durham, NH. Three lesson plans using system archetypes and/or the Systems Thinking Playbook which help children understand the process of thinking and acting systemically, and how this method can be used to understand specific curricula. [Systems Education, Causal Loops, Cross Curricular, Social Studies, Elementary School, Middle School] ($1.00)

SYSTEMMH ***Systems Thinking in School Administration: Part I.*** Matt Hiefield
An interview with Rick Miller, principal of Sunset High School, in Beaverton, OR, focusing on how staffing, class size, etc. are issues best understood using systems thinking. [Systems Education, Administration, K-Adult] (50¢)

CROSS CURRICULAR

USINGSJH ***Using System Archetypes in the Classroom.*** Jennifer Hirsch, Joan Scurran, & Scott Suter
From Catalina Foothills School District, presented at the 1998 Systems Thinking and Dynamic Modeling Conference in Durham, NH. Three of nine printed archetypes are presented with suggested classroom uses: Shifting the Burden, to reduce student blaming and excuses; Escalation, to analyze the Industrial Revolution; and Success to the Succcessful, to analyze work habits and motivation. The suggested activities are geared for middle school but the lessons are readily adaptable for any level. [Cross-Curricular, Causal Loops, K-Adult] ($1.00)

SCIENCE

BOTTLEML ***Soda Bottle Water Rockets: Build the Rockets and the Models.*** Martha A. Lynes
Prepared with the support of the Gordon Brown Fund. In this unit, students design, build, and launch soda bottle water rockets and, after an introduction to the basic principles of system dynamics and STELLA modeling, build models of their rocket systems. The complete STELLA models are included. Although this is a high school physics unit, the introductory modeling lessons, the modeling suggestions, and the learner-centered approach can apply to other grade levels and subjects as well. [Science, Dynamic Modeling, Simulation, Cross Curricular, High School, K-Adult] ($2.00 paper only, $7.00 paper + models on disk)

SOCIAL STUDIES

STUDENSY ***Students Taking a Systems Approach to Drinking and Driving.*** Stephany Yerger
From CC-STADUS. A member of the class of 1999 at La Salle High School reports on the project she and classmates undertook to create a tool for hands-on alcohol education using STELLA. Model included. [Social Studies, Simulation, Science, Cross Curricular, Middle School, High School] (50¢ paper only, $5.50 paper + model on disk)

SYSTEM DYNAMICS

DESIGNJF ***Designing the Future.*** Jay Forrester
Jay Forrester's speech at the University of Sevilla, Spain, in December 1998. A discussion of system dynamics and how it is the cornerstone for the understanding of social and economic systems, which will be the new frontier. [System Dynamics, Adult] ($1.00)