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WRITING AND MODELING: USING A NOTEBOOK TO LEARN ABOUT SYSTEM DYNAMICS

by Timothy Joy**.** This monograph was made possible through a generous grant fromThe Gordon Brown Fund.

The intellectual step of distinguishing a stock from a flow to constructing system dynamics models is awkward and many stumble, but using a notebook in this early stage can help students (and teachers) make these strides with some ease and purpose. Teachers will find the necessary guidelines for using a systems notebook as well as a long list of writing and mapping exercises that integrates the writing process with system dynamics instruction. These guidelines and exercises are especially helpful for middle and high school students who are building some early confidence in basic stock and flow mapping as well as those students ready for model building and testing.

The writing process offers not only a good metaphor for model building; it also offers a means to composing the models themselves—a clearly told story will help the model builder, and a well built model will help the story teller.

Students discover they cannot write accurately and effectively without a sound understanding of the feedback, nor can they trace the model feature terribly well without having appropriate and consistent language. The more fluent students become at telling the story, the more facile they are at building the model.

Every page of a systems notebook reveals the mental model of its creator. These are what we wish to expose, to lay bare, to test, to evaluate, and ultimately to improve—we want students (and ourselves) to have better mental models.

Good writing and good modeling go hand in hand.
–Jay Forrester, 23 February 2000

Writing wells up from a deep tradition in human thought and lifts the writer into a realm of creative, though disciplined, thought wherein various choices hold the author responsible for an idea called "story"—printed on a page, awaiting an audience. Before this, however, a writer reviews, revises, edits, rewrites whole scenes, possibly tossing out some story elements as he attempts to weave a seamless tale, what noted author John Gardner called the "fictive dream." And then a reader accepts the dream, borne along in a plausible story that rings true and takes a reader to some place he had not been before.

Writing, with all its leaps and minutia, offers not only a ripe metaphor for building computer models, it also offers a means to compose the models themselves, a way to test them, to hone

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MURDOCH MIDDLE SCHOOL, Part IV

by Dan Barcan

Anyone who visited Murdoch Middle School this year would be able to see that enormous changes have taken place since the day it opened its doors in 1996. It is now housed in a building that easily holds over one hundred more students than the prior one. In place of donated computers cobbled together by parent volunteers, students learn to use technology in a shiny new lab. A large, well-lit room provides ample space for physical activity during Massachusetts' long winters – a vast improvement, according to physical education ("challenge class," at Murdoch) teacher Russ Reid. And each Wednesday afternoon, students don't go to their regular classes. Instead, they head off to activity periods, run by a mix of parents and teachers.

According to one of Principal Walter Landberg's weekly letters home, the school started these activity periods as a way to bring students, parents, and teachers together in a less formal – but still educational – setting. Katie Starbuck,

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UPDATES…

DynamiQUE*ST*

The fourth DynamiQUE*ST* was held at WPI on Friday, May 9th. Forty-four students and twenty-nine adults participated in a day of presenting and coaching projects, playing systems games, and working together in a group problem-solving exercise. The students' projects showed increasing systems understanding, and they seemed to enjoy presenting them as much as the adults enjoyed observing and discussing them. A description from Jeff Potash, who chaperoned the group from Vermont Commons School, sums it up:

> Our kids were universally thrilled with the full course of events organized during the day. The "newbies," in particular, were amazed by the quality and authenticity of the coaching.
>
> What intrigues me (and several of the teachers with whom I shared the coaching feedback) are three of our students who truly rose to the occasion in presenting their work. All came away with a far greater sense of confidence and self than when they arrived. One student, in particular, who is altogether silent in classes here, was amazing in his verbosity and polish at the event. After he'd finished explaining his work to Jim Lyneis and Khalid (Saeed), he came back to me and said that he thought he'd "taught these people something!"

The day's success again depended on work of both teachers and students from all six schools who attended—from Carleton District, Ottawa, Canada; Williston Central, Williston, Vermont; Vermont Commons, Burlington, Vermont; Murdoch Middle School, Chelmsford, MA; Harvard Public Schools, Harvard, MA, and Carlisle Public Schools, Carlisle, MA—and the generous donation of time by the coaches. WPI's facilities were a perfect location for the third year in a row.

Students participating ranged in age from fourth graders, whose topic was *Modeling a Savings Plan for College*, through middle and high school, to the Ottawa students in grade 13, who presented on *Are We in time to Create a Sustainable Infrastructure Based on Hydrogen?* From nuclear weapons to homework, from disease control to fish populations, from air polution to obesity, from global warming to rumors, from cookies to the Federal Reserve Fund, the students consistently met the challenges of their projects. Coaches and observers were consistently delighted by the skills displayed by the young people presenting their posters.

The fifth annual DynamiQUE*ST* is scheduled for May 14th next year, again at WPI.

EDITORIAL

As the school year school year winds to a close, we at the CLE are looking forward to a summer of relaxation, punctuated by the International System Dynamics Conference in New York City. At the ISDC, a group of teachers is joining John Sterman to have another look at his bathtub dynamics with K-12 students. The Bathtub Dynamics paper is available to download from http://web.mit.edu/jsterman/www/Bathtub.html.

We all enjoyed seeing the numerous projects at DynamiQUEST, and are thrilled to be a part of that ongoing effort to get professionals in the field of system dynamics together with students to share ideas. Each year, the students seem more comfortable with systems skills, more confident about tackling difficult topics, and more poised in their presentations. We came away mightily impressed.

On page 10 in this newsletter, you will notice the announcement of STELLA version 8 from High Performance Systems. HPS has generously offered a discount to the newsletter readers. Version 8 is the final legacy of Barry Richmond, founder of High Performance Systems and creator of STELLA, the first user-friendly visual system dynamics modeling tool. He was working on this version when he died suddenly last summer.

May your summer renew your spirit for another year and may your mind be busy with creative plans for the new school year.

Take care,

Lees Stuntz (stuntzln@clexchange.org)

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the model's language, to edit its ideas and logic, to tell its compelling story. Indeed, composing a model without composing words may set the modeler adrift. It is for this reason that these notes are set down—some guidelines and hints for you and your students as you venture into the tangled beauty of system dynamics.

Keeping the students' work in notebooks

Writing is not hard. Just get paper and pencil, sit down, and write it as it occurs to you. The writing is easy—it's the occurring that's hard.
–Stephen Leacock

George Richardson once reported that somewhere in Jay Forrester's house reside all the notebooks from Forrester's earliest days in system dynamics right up to the present—all his drawings, all his annotations, all his equations, all his assays into new territory, all his lucid writing. For a moment, we drenched ourselves in that thought: "Oh, to look at those books." And, so, our students should learn from the master: keep a notebook to capture *every* system dynamics thought.

A number of stationers make notebooks available, but these favorites I use in my English classes:

- Mead Composition Notebook, approximately 9" x 7", college-, wide- or quad-ruled
- Scientific Notebook, approximately 8 "x 11"

They have a serious side to them: no spiral or glue binding. Go with a sewn binding. Of course, choose what you want, but I have always preferred that students compose in something closer to a book than a mere spiral notebook. Even binders, which allow considerable flexibility, do not have permanence, nor will they necessarily maintain the historical flow of a student's intellectual journey, a clearly important piece of their record.

Students will draw reference behaviors in time graphs, paste in short stories or excerpts from novels and identify stocks and flows, draw and annotate models, cut and paste news articles from all manner of periodicals, draw graphical converters and write the story of the line, draw multipliers—then defend or refute the line which defines it, amend their own models, zoom in on one sector of a model and elaborate, draw ALL the models that each student in the class may build, write equations and compose a story to replicate it, record (or paste) graphical and tabular outputs and explain the results, compose questions, tell feedback tales, trace the influence of a multiplier on a single feedback loop, tell how loop dominance shifts as a system moves through time, paste in system jokes, compose drafts for SyM•Bowl papers. In short, students ought to commit some measure of systemic thought to paper EACH day. So it needs to be a big book.

Some students will want this to be a private place, but make it plain that the notebook is NOT a diary; rather, it is an intellectual record that has some measure of public access to the teacher and, possibly, classmates.

<u>Organizing the notebook</u>[1]

- **Maintain an easily adaptable table of contents or index.** Many writers simply leave the first two or three pages blank (some choose the last pages), allowing the user to label each day's entry with a brief descriptor so that models and ideas would be easy to find:

Date	Brief title	Page #
9/12	Pop. model in equilibrium	6
9/15	Forrester feedback quotation	8

- **Always date and label each entry**. Whatever index you establish is worthless without this information. Keeping a page-by-page record is as crucial as keeping the Table of Contents.
- **Be neat.** Someone else will need to read this, not the least of whom is the teacher. If a student's handwriting borders on the illegible, ask for printed documents taped or glued in. Also, students will be reviewing their own work from time to time, so legibility is very important.
- **Each model entry must include a clear diagram and labeling.** This is just obvious. The continuous hand drawing and writing of *all* models or causal loops or notes help students internalize these ideas. Drawing stocks and flows reinforces their ubiquity in the world.
- **Each model entry ought to include a reference behavior graph.** Some class assignments, as mentioned above, will include models from news items, and even these models will need graphs, even though they are thoughtful guesses. The model has *some* meaning alone, but the structure and its conceptual algebra come to life with a graph. Every entry that pairs a graph with a story stitches together these disparate fabrics.
- **Each graph ought to include a one- or two-sentence summary statement.** Before a note-creator turns a page past a graph, the meaning of the graph—its key lines, its abrupt shifts and plateaus—begin to fade from clarity. Every graph needs a narrative corollary.
- **Each model entry should include a one- or two-sentence summary statement**. George Richardson calls these "lessons-learned bullets," a brief catalog of what's important about the model. It's the "so what?" of the model. The continuous practice of *narrating* some part of a model underwrites a young modeler's capacity to learn the language of systems.

[1] Barker, Kathy. ***At The Bench: a Laboratory Navigator***. Plainville, New York, Cold Sspring Harbor Laboratory Press, 1998.

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- **Leave space for later notations and teacher commentary**. This can easily be done by leaving a 1" to 2 " margin on the right or left. Even students will want some notation space, since they may—months later—revisit the model and note additions or corrections.
- **Weekly summation**. One sentence, perhaps a question, that captures the day's or week's thoughts. You may encounter some resistance initially, but this will pay off as students start out *the next day*.

Notebook types

Notebook style, akin to fishing style, depends on the keeper (or the fisher). It also depends on the purpose. Here's a brief look at a few styles, though you will likely want your students to do a little of each. Each has its advantages.

- *The dialectic*: students record (or paste) information on the left-facing page only, leaving the right-facing page for commentary, using lines and arrows back to some particular item in the model or article. Essentially, the object studied is like a specimen, and notations made surround it. Some students use colored pens/pencils. This may be best with articles, models, or parts of models you would like students to think about for a while. Such entries are sometimes called reflective, or if you collect jargon, "metacognitive."
- *The historical record*: students record models, notes, data sequentially, completely, leaving annotation and organizational notes for later. It's good to ask students, say, once a week (or biweekly at the least) to revisit all the previous work and make summary notes. This method provides a detailed accounting of a semester's (or a year's) study. Therefore, *everything* should be in here: every model, every graph, every conclusion. Items or documents that do not fit ought to be filed in an easily accessible place.
- *The classic copybook*: students copy *verbatim* very sound models—diagrams, equations, graphs, all of it. The notion here is that writing is *visceral, sensual* as well as intellectual. Copy three pages of John Steinbeck's *The Grapes of Wrath* and your capacity to compose a good sentence improves. Imagine the impact of copying the *Urban1* model or Forrester's *World2*? I would not advise this in the first week, but, eventually, this is a valuable tool. *Special Note*: These must be handwritten! The pace of doing by hand forces the copier to ingest the model methodically, to *feel* the connection drawn from, say, capital investment to pollution. And there is time to consider that connection. In the glory days of classical rhetoric, the copybook was the warm companion of monks and scholars throughout Christendom.

Helping students do this

- Most students are NOT in the habit of such painstaking and habitual note-taking. You will need to coax them. For instance, you might want to collect the notebooks every two or three days in the first two weeks just to move them along, keep the feedback swift and upbeat, and then back away to a more tolerable, biweekly regimen. They will come to thank you for it.
- Show them good examples. If students have a clear model, they have something concrete to emulate. This ALWAYS works.
- As you well know, modeling is an intensive exercise and students will need you to keep them calm. They will lose track of time and perhaps forget to compose the summaries. A gentle reminder that five minutes remain before the bell, for example, allows them time to collect themselves, note what's necessary, and perhaps compose a statement or question.
- Students will have (or ultimately establish) their own methods and preferences in the notebook, but initially you would do well to give considerable direction early so they at least have a clear method. After some familiarity with a common method, students could pursue their peculiar means (and they will, whether you release them or not).
- Pay close attention to commenting in the book. Occasionally, ask students to simply exchange notebooks among themselves, a habit that should eventually come as second nature. See further comments in "Evaluating What Students Give You."

As in all things, some thoughtful attention to minutiae early on will establish good habits of thought and pay off profoundly. Remember, these are minds and ideas at the beginning of new exercise—be gentle and uplifting.

Telling stories

It's all a matter of keeping my eyes open.
–Annie Dillard

At a most primary level, students need to recognize a stock from a flow. This takes practice. From the outset, the teacher ought to present students with myriad opportunities to seize upon these recognitions: use articles from newspapers such as those from the Science section in *The New York Times* or The West section in Portland's *The Oregonian*. Students paste in the article and draw a stock/flow-feedback diagram, or perhaps a causal loop diagram, depicting the system as they see it. Such practice makes thinking explicit and can serve as an act of discovery: discerning stocks and flows clarifies thought and leads to insight. For obvious reasons, start with small articles, relatively apparent systems, and then ratchet up in complexity as the weeks go by. But don't be surprised if an ostensibly simple story becomes complex! Stock and flow diagrams, as well as their reference behavior graphs, are rich, leading to discussions that will make every social science teacher jealous of you.

Telling stories is a good habit to get into. Regardless of how simple a story may seem initially, just tell it. A good story has all the markings of a good model: a clear focus and some internal consistency. Here are two I tell every course:

> Rain fell steadily for two hours; then a squall moved through, dumping huge amounts of rain in about 15 minutes. The storm drain overflowed.

and

> Nick bothers Mr. Joy every time he talks, but Mr. Joy can usually take it. Some days Mr. Joy ***can't*** take it because the other students have been ridiculing him constantly. When Nick talks on such a day, Mr. Joy becomes enraged and throws chalk. Then, he's fine.

I tell these about a week or two apart. The second initially overwhelms them because students often see it as too complex. However, someone will come to the rescue and note that these two seemingly different stories carry a similar structure. Just how important is that? When students note the similarity of structures, this is cause for widespread jubilation; for when gold is struck at any time, halloo and shout: here, students have discovered that fabled lode, the generic or archetypal structure, a core model piece that transfers across disciplines.

We all know that any ostensibly simple system rapidly sends tendrils to other systems. And this is quite instructive, not only to students, but to any storyteller—you're on to something big when the story taps a source for another story. It is the sign of a well-told story and a well-built model.

If it comes to it, you may need to talk to yourself. Write brief stories in your notebook. Collect a dozen, two dozen three- to ten-sentence stories that convey apparent stock/flow-feedback structures. (See "Just Right Stories" in the next section.) Note them, for instance, as you walk around the block on a fall day: trees sloughing leaves—a leaf stock conveyed to another locale at a varying rate—students can certainly draw the reference behavior and a discussion might follow about a critical biota. Start with leaves and, if so desired, Chaucer and Frost will ensue.

Writing projects around the country give strong evidence in this key point: when teachers write with their students, student writing improves. Why? Teachers who write provide a model of thoughtfulness students can *see*; teachers and students are more likely to form the so-called, and much desired, "community of writers," wherein each contributes writing and criticism; and students, therefore, are even more likely to contribute their writing samples and writing judgments when there's a payoff; students see teachers as experienced writers rather than solely as reservoirs of writing knowledge meted out in daily lessons.

It is so, also, in modeling. Teachers who tell modeling stories, search out stock/flow-feedback stories in newspapers and magazines as well as the world around them, will engender students inclined to do the same. Since students will often work on independent projects, this practice of seeing systems on their own is crucial.

There are numerous writing analogs for modeling, but the upshot is this: the instructional emphasis on teaching the writing *process* over the writing *product* has gained acceptance because it does two things: it closely follows what actual writers do, and, it works—student writing improves. So, too, in teaching modeling.

Students will gain felicity as they tell systems stories. It is no surprise, of course, that the more stories one tells, the easier it is to tell them. You can likely see the feedback loop in your head. And the telling redounds in that other critical area—building computer models. In other words, storytelling—that most primal art form—informs and refines modeling, giving the teller and the modeler a *skill* in rendering structure to meaning, a *sensibility* about feedback relationships, and a *template* to discern patterns over time.

<u>Just Right short stories for drawing small stock and flow diagrams</u>

These fifteen "Just Right" stories are ideal class starters. Start class by writing one on the board and ask students to create a stock and flow diagram that captures it. It is wise to implore students to stick *primarily* to stocks and flows, to minimize converters and connectors. Doing so will keep students focused on the key elements in the system. Certainly, *some* use of connectors and converters is inevitable and even necessary to convey connections and feedback. True. However, the key to these exercises is stock and flow mapping.

Allow students a few minutes to draw, to talk, to compare their drawings, and then ask two or three students (with differing models, preferably) to draw their models on the board. Students should tell the story of their map, to include their decisions to leave some things in and some things out. Once done, ask other students to agree or disagree, but also to state their case on their disagreement. These discussions on the nature and assumptions on stock and flow construction help build up student felicity and understanding with maps.

You will note these stories are both universal and local; that is, most of them can be read and used in *any* class, and some of them are too local, but might easily be adapted to your purposes. For the narrow local stories, read them to get the gist and then change the story to fit your geography or political hot buttons. I include some *possible* solutions for a

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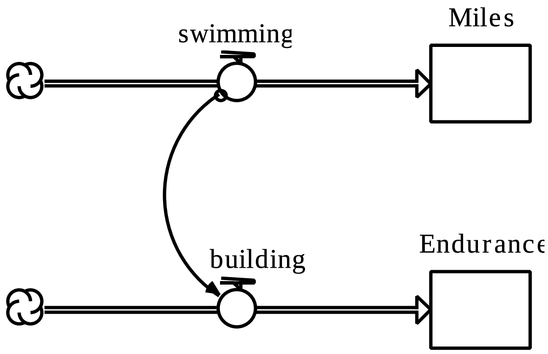
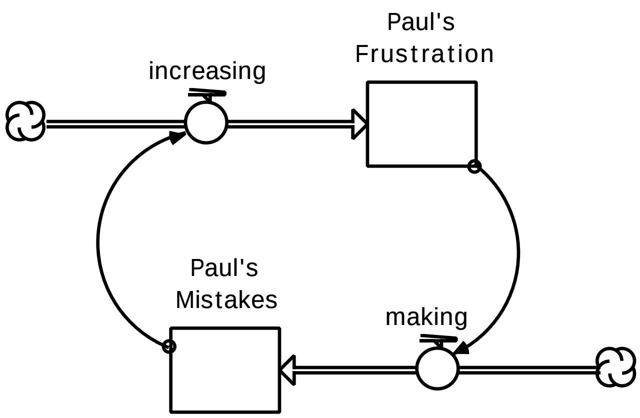
few just to get you started. Last, these are relatively easy to come up with, and you'll soon have a long list of your own.

1. Swimmers build endurance by swimming miles every day. For example,



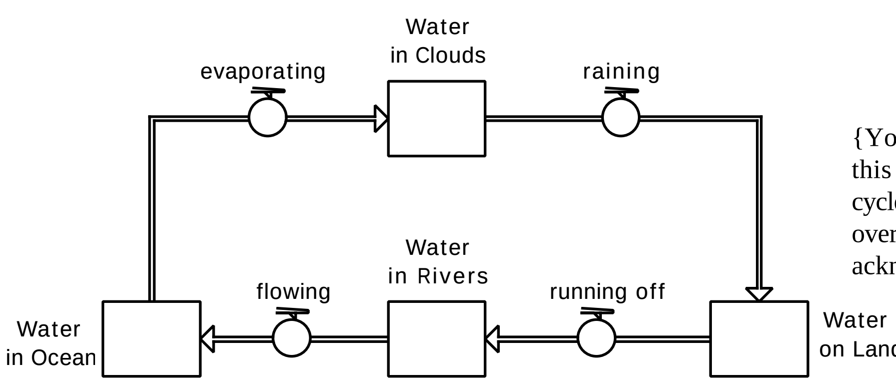
{An insightful student may see that an outflow from *Endurance* would make sense here. Let the student tell why.}

2. Paul gets frustrated a lot. The more frustrated he gets, the more mistakes he makes. The more mistakes he makes, the more frustrated he gets. For example,



{Technically, there are intervening graphical functions between stocks and flows that control the rate based on the stock level. Depending on the expertise of your students, go there or avoid it. The key here is the stock to flow connection.}

3. The sun's energy evaporates water from the ocean, which then falls as rain on land, and then runs into rivers and back to the oceans. For example,



{You will likely get some variations on this one. Keep students focused on the cycle and, in this early stage, do not worry overmuch about differing rates, except to acknowledge that they exist.}

4. It rained all day, water in the street draining into sumps. Then, a squall moved through, and in about ten minutes, the sump overflowed. Once the squall passed, the water drained and then light rain followed.
5. Mr. Joy's anger often increases because students continuously degrade him, but he manages to control it. One day, Max insulted him and it was more than Mr. Joy could bear. He yelled and threw chalk, but then he was fine.
6. Chris did the exercise dutifully for about two minutes. Then, as he grew bored, he started telling jokes and playing with software. I yelled at him, and he stopped . . . for a while. Then, he just did what he wanted.
7. As the school year goes on, more and more students cheat. Teachers remind students of the consequences of cheating; a few students are caught, but cheating seems to just go on.
8. Sheila's work excels, and her confidence increases. Her higher levels of confidence inspire further improvements in her work.
9. As average speed on a freeway increases, the State police set up more speed traps, which brings the average speed levels back down. (HPS-Inc.)
10. As fans stream into the stadium, they wait in lines at the turnstiles, always choosing the shortest line.
11. People have been moving into the Sunnyside area since Interstate 205, Kaiser Medical Center, and Clackamas Town Center were built 25 years ago. Even though house prices are high and traffic is horrible, people are still moving in.
12. The more homework Hercamer is assigned, the less he wants to do it.
13. "People move here for the view. But if people move here, we won't have the view anymore." (A frustrated Californian from the Central Valley, Fall 2002)
14. The more congested the traffic gets, the more likely we are to add some lanes. But, after we add lanes, it seems just as congested as ever.
15. Why is it that when I make minimum payments, I can never seem to make any headway on what I owe?

Finding stories

Let the fiction grow out of the land beneath your feet.
–Willa Cather

Once your students *hear* stories and can decipher stocks and flows in a manner similar to deciphering setting or character or metaphors, they are then ready to search on their own. Jay Forrester is fond of a story about a young modeler who once told him that system dynamics had helped him read the newspaper. One of the byproducts of such reading is that it underscores the ubiquity of systems as well as the occasional gaping holes in the logic of some journalists or the people they are reporting on. Scott Guthrie (Wilson High School – Portland, Oregon) has used this specific tool extensively; his students, over time, garner a keener understanding of the *nature* of a stock and a flow. Further, George Richardson recently proposed that identifying stocks and flows in stories, whether as news or literature, comprises a foundational piece for system dynamics, *a skill set that children in primary grades can master*. Consequently, such a practice ought to be in *every* systems related course, whether in the sciences or the humanities.

Students at La Salle High School (Portland, Oregon), a Roman Catholic institution, take a junior religion course called Social Justice. A pervasive theme of that course, as distilled through centuries of Catholic social teaching, is the *common good*: sustaining the dignity of all humans in the face of social or political challenge. Most recently, the Catholic Bishops of the Pacific Northwest issued *The Columbia River Watershed: Realities and Possibilities*, a reflection on the Columbia River Basin as "sacred waters." Juniors examined portions of that document and studied a few elements of the systems involved in that grand story encompassing British Columbia, Montana, Idaho, Washington and Oregon. From the mythos of Native American lore to the divisive rhetoric of dam politics, each vignette of the overarching story of the Columbia carries downstream a variety of system structures, a current rich for discussion among students.

An effective means of getting students to this level of discernment is for them to do on their own what you began earlier, providing simple system stories from news sources. On a bi-weekly basis, for instance, students come to class with articles and a stock/flow-feedback drawing that they share with the class by drawing it on the chalkboard. All the other students draw the same diagram, leaving space below or on an opposing page for amendments, disagreements, and any notes. Once drawn, the presenter tells the story using the diagram, draws some conclusion about the article and/or the model, and then takes audience queries or assertions. Usually, sessions can occupy a full period, but do not worry whether this time spent has merit. It has. Any prolonged discussion using stocks, flows, and feedback loops is an acute intellectual exercise that hones a person's systems sensibility.

End of Part 1.

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The second half of Tim's article will be published in our next newsletter. The article in its entirity will be available shortly from the CLE website, clexchange.org, catalogued under Implementation as IM2003-05WritingAndModeling.

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a fifth- and sixth-grade teacher who coordinates the program, said that the adults teaching the courses chose the topics according to their own interests. Students, too, pick by personal interest.

And it appears that there is something for everyone. Students can busy themselves by learning to quilt or going for a run. Some spend Wednesday afternoons cooking latkes; others practice African drumming or Ultimate Frisbee. One group of kids reports on these activities while running the school's newspaper. And another, under the direction of Waters Foundation Mentor Janan Hamm, learns to use the tools of systems thinking and system dynamics.

But wait. What's systems thinking, a key facet of the school's academic program, doing in the activities period? When did it take on the same status as Ultimate Frisbee? Walter Landberg, now in his second year running the school, says that it really hasn't, calling it "equal to other parts [of the school's curricula] as a priority." He describes systems thinking as harder to implement than the "three r's," because people haven't been trained, either formally or informally. Right now, he said, "it is an icing that doesn't always get put on."

Icing? As in an extra? Something unnecessary? Not quite. Landberg is quick to point out that he would certainly prefer systems thinking to be visible in the school in more substantive ways. "It should be integrated with the other subject matter," he says. "Not as a chunk dropped in or added." Right now, though, he says, the capacity simply doesn't exist at the school to do this.

When Landberg began as principal, in the 2001-2002 school year, he took over a school in the midst of significant changes. In addition to the departure of both the school's original principal and one who had served in the role for the 2000-2001 year, all of the founding teachers had left the school by June 2001. Add to that the school's growth before the larger building opened this year, and throw in the oft-cited teacher shortage, and you begin to get an idea of what Walter Landberg's summer was like. It makes sense that he wouldn't turn down a talented candidate simply because he or she didn't happen to know much about systems thinking. He estimates that, right now, half of the teachers understand systems thinking and system dynamics.

The Board also experienced turnover. The two last members of the group that had written the charter and comprised the original Board vacated their seats this year. It so happened that they had a good deal of experience with systems thinking themselves. When I asked current Board members about the current state of systems thinking in Murdoch's classrooms, only one person answered me, saying that as a new Board member, she wasn't familiar with the curricula.

It appears, then, that even if Murdoch had some people – both in classrooms and on the Board – who were able to get systems thinking integrated into various parts of the curricula by the school's fourth year, they weren't able to get it to stick. In *The Challenges of Infusing System Dynamics into a K-8 Curriculum* (available as SE2001-09InfusingSDIntoK-8 on the cle.org website), Debra Lyneis and Davida Fox-Melanson chronicled a similar challenge in the Carlisle Public Schools. Carlisle's program is more mature than Murdoch's; it also involves more mentors and classrooms. However, mentors in Carlisle still wrestle with the challenge of making systems thinking and system dynamics curricula activities work without having a mentor present each time they are taught.

One might say that Murdoch is only a step behind this more advanced program, then: systems thinking is currently present in isolated spots throughout the school, but it isn't spreading. And it relies on specific people to exist at all. Landberg says someone looking to find systems activities in the school would see them, for example, in the challenge class, where Reid plans many of his non-competitive games by using the *Systems Thinking Playbook* (Pegasus Communications Inc., 2001).

During the 2000-2001 school year, Reid worked with the school's mentor each week to integrate systems principles into his classes. While there was no modeling that took place, he received a significant amount of one-on-one training that is still providing benefits to the school in the form of his ability to continue the program. However, he pointed to the personnel changes over the past few years as a hurdle in the school's development. "Intermediate people," – in other words, those who had already learned the basics of integrating systems thinking and system dynamics into their classrooms – "get frustrated with being in the same place every year." He does not, he said, work to train other teachers about what he does, explaining that the school's current structure and size don't facilitate such collaboration.

Greg Orpen, who serves as the school's mentor along with Hamm, is aware that the mentoring team, as well as other experienced teachers like Reid, isn't providing the support he wishes they were. "Before you're effectively mentoring," he says, "you need to feel comfortable [teaching systems] yourself." He reports that he and Hamm have spent much of this year learning more about systems thinking and system dynamics and networking with other, more experienced schools.

One of his most successful moves was to recognize that the expertise need not be transmitted through only the mentors themselves. When Murdoch's fifth- and sixth-grade teachers wanted to plan a unit that included some systems thinking components, he realized that the best way to help them would be to connect them with some teachers in Carlisle. How did he do it? Simple: he taught fifth- and sixth-grade for a day, freeing up the teachers to meet with Carlisle's. The result has been increased use of behavior-over-time graphs in a "Patterns of Change" unit, and a unit which helps students draw "connection circles" to analyze literature.

Orpen has also experimented with working at the other end of the spectrum: actually teaching systems-based classes with other teachers. He recently planned a lesson with a teacher who was teaching about population dynamics in China with a pennies-in-a-cup version of the In-and-Out Game[1]. As the teacher helped the students divine the systems principles at play, he drew the stock-and-flow maps on the board.

Normally, he says, systems curriculum appears in small spots: a question on a test that requires students to draw a small stock-and-flow map, a small loop diagram that illustrates a point from a history lesson. You might even miss it altogether if you weren't looking carefully, he says.

"As a teacher, knowing that I have a goal to help students think systemically, whether now, this month, or next year, makes the class work differently. But walk in off the street, and it's not in your face." And he is clear about how he means to spread it to the rest of the staff: "We're waiting for them to just be 'whelmed'," he said, referring to the enormous amount of work that recently went in to overhauling the school's two-year curricula. "It'll spread when people see success."

Right now, Orpen's organic method for disseminating the ideas is the only one at play. Both he and Landberg agree that there is no mandate from the Board or principal to use systems in any class, though people were encouraged to attend a recent conference as an introductory step. Landberg plans to begin next year with specific student goals for systems education, and then use those goals to hold staff accountable for getting kids there.

He was, in fact, rewriting the school's accountability plan – a required document for charters, in some form, in nearly every state – as we spoke. Massachusetts insists that all charter schools spell out exactly what students will do and how well they will do it. If systems thinking and system dynamics success appears in the plan, and the students don't demonstrate it, Landberg will have to answer to his Board, and the Board will be answering to the Department of Education.

Murdoch's story, then, seems to be illustrating the principle that learning – and, by extension, improving skills – depends on feedback. In the early years, student learning slowed as kids waited for teachers to learn how to assess system dynamics work. Then, after a few teachers learned to do this, others found themselves stuck as they awaited instruction and comment from their more experienced colleagues. Finally, when most teachers were finally using systems thinking and system dynamics in their instruction, the school saw problems in the quality of the student products, since the teachers weren't rigorously examining their own work.

Now, in the school's eighth year, even the principal admits that he can't provide his mentors feedback on how they are doing. Sure, he says, he could tell you that he isn't pleased with where the program is at present, and that he knows that his leverage lies in helping the school set clear goals. But right now no one at Murdoch believes that he or she has the expertise to instruct other adults about how to teach systems-based curricula.

They are, as they get themselves up to speed, doing a number of other impressive things. Orpen has redefined what exactly a mentor's job is, to allow his teachers to receive some help from more experienced colleagues – though those colleagues teach in another school. Landberg is insistent upon systems thinking and system dynamics appearing prominently in the school's new accountability plan. Other teachers are incorporating what they can, when they can – be it after school or in isolated lessons or units.

So if we were to graph the school's progress in this area, it wouldn't be the elegant exponential growth curve we might all hope for. Though the staff we might refer to as Murdoch I (roughly, 1996-2000) had to compile a large binder of units and projects in order to renew the charter, and though they included various systems thinking activities, those binders and papers were not of much use to Murdoch II (roughly, 2001-present). Having access to complicated or new curricula sometimes means actually having access to its author. There would certainly be points over the eight years when the graph would show improvements taking place, but there would be plenty of others when it would drop downward or plateau.

But first, we would have to decide what exactly would go on the graph's y-axis. Number of lessons used? Number of teachers who use systems thinking and system dynamics? Number of kids exposed to the concepts, or to the tools? Which tools? What about tracking the impact, since Landberg mentioned that the current Board "has put a lot of focus on raising academics – seeing higher test scores"? These are the questions that get answered in the

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1 See ***The Challenges of Infusing System Dynamics into a K-8 Curriculum*** (available as SE2001-09InfusingSDIntoK-8 on the cle.org website) or the CLE Fall 2002 Newsletter.

Some thoughts on using STELLA in math and science classes…

It is Friday, a time I am released from teaching math to help facilitate the use of system dynamics throughout the school. I enter the eighth grade science class where the teacher is giving some last minute instructions regarding a homework assignment. He then asks the students to get out their lab books and look at the data from their ramp experiment. In this experiment, students have run toy cars down a ramp and collected data. Today, students will use their experience, along with a STELLA model, to deepen their understanding of the physics of motion.

I turn on the computer and project onto the screen a STELLA model of a car traveling down a ramp. The model looks complicated and the students are duly impressed. A perfect set up for the first task: “ Explain to your team mates why the model really isn’t as complicated as it looks.”

The students are silent for a moment while they stare at the model and then erupt in conversation. One by one the teams figure out what is going on: the stocks and flows are similar to a model they built two days earlier in math class. There the students were asked to build a model that would help them figure out how long it would take a coin to hit the floor when dropped from a height of three meters. Both models show how an object moves under the influence of gravity.

I talk about today’s model a bit and send each team of four students to a computer where the ramp model has been loaded. After doing a number of simulations, copying graphs, answering questions posed by the science teacher, and checking predictions they made earlier in the week, student are asked to return to their seats. We run the distance graph on the computer and the science teacher asks students to identify the point at which the car leaves the ramp. Different teams make their prediction and a heated discussion ensues. After some dialogue among the teams, the class narrows it down to two possibilities.

There is some talk about what ‘the answer’ is but students know better than to ask for it: in this class they have to figure it out for themselves. One team suggests graphing the car’s velocity and distance graph on the same graph pad. After doing this a cheer goes up as a student explains: “The car reaches its maximum speed at the same time that we predicted earlier. The car goes fastest at the end of the ramp, so we were right...”

This class is a good illustration of how system dynamics is used in our curriculum. By the time that students analyze the ramp experiment, they have already made countless numbers of Behavior Over Time Graphs in different subject areas to communicate their thinking. They have used a systems component in every science lab this year. They have learned how to navigate in the STELLA environment, and they have built a series of simple models in math class to help solve word problems. Students see system dynamics as another tool to get desired results: understanding and communicating complex ideas that are part of the curriculum.

An important stimulus in my desire to teach modeling with STELLA came from the reappearance of simple ideas in different contexts. Consider word problems. Like many math teachers before me, I have put a lot of effort into developing strategies to help students understand and solve word problems. While some students thrive on the challenge of these problems, many find the process of ‘translating’ words to equations daunting. One of the reasons for this difficulty is that the contextual story hides the underlying mathematical structure.

It took me a while to appreciate that building simple STELLA models helps students uncover these structures for themselves. STELLA allows students to model what is described in the text, rather than abstract it. I believe that this is what Barry called operational thinking. After a few introductory lessons, my students are asked to model simple word problems, none of which contain feedback. I looked for a good source of problems and ended up perusing and using a variety of algebra texts. In the process of doing this it, it became apparent to me that students could model well over half of the word problems in a typical algebra book, all within the first month of the school year! This was astounding, and reason enough for an algebra teacher to use STELLA. I didn’t have to convince students that many word problems are built upon a similar underlying math structure - they discovered that for themselves in the process of building models.

It took me a while to appreciate that building simple STELLA models helps students uncover these structures for themselves. STELLA allows students to model what is described in the text, rather than abstract it. I believe that this is what Barry called operational thinking.

It now is a recurring pleasure for me when students exclaim after modeling word problems for a while, “Mr. Quaden, these problems are all the same.”

Indeed they are...we are ready to move on!

Rob Quaden
Waters Foundation Mentor
Carlisle (MA) Public Schools

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school's accountability plan and allow the real work to begin. If last summer Walter Landberg had his work cut out for him in terms of getting a new building filled with kids and teachers, as well as ensuring the smooth completion of the construction project, then this one may hold fewer resumes and less saw dust, but it looks to be no less busy.

This article, catalogued as PH20003-01MurdochMSIV, is available free of charge at clexchange.org

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