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How Is This Similar to That?

The skill of recognizing parallel dynamic structures on center stage

Linda Booth Sweeney

Author's note: While making my way through Harvard's doctoral program in education, I found myself endlessly explaining what was this thing called "systems thinking." Like Sisyphus pushing the boulder uphill, I had a burden to carry and a lesson to learn. By the time I graduated (seven years later), I had learned to place systems thinking skills in the context of more conventional educational thinking skills, in order to communicate with my academic colleagues. This article is intended to put systems educators' daily work in context for educational researchers and to highlight a central skill for schools seeking to teach students to see, understand, and ultimately affect the systems around them.

Many thanks to Tracy Benson, Rob Quaden, Larry Weathers, Janice Malloy and Lees Stuntz for their helpful comments.

How Is This Similar to That?

In a handful of classrooms across the country, middle and high school students are learning about the dynamics of systems by experimenting with a rain

barrel. In the activity, one scenario has water flowing into the barrel at a greater rate than it is flowing out. Students are asked to consider what happens to the level of the water in the barrel. Now the scenario changes: the water flowing out of the barrel is at a greater rate than the water flowing in. What happens to the water level then? After using this hands-on model, students are asked to recognize the same *structural dynamic*¹ in other situations having nothing explicitly to do with rain barrels, such as: (a) intravenous drug infusions (or multiple injections, equivalent to buckets being poured into the rain barrel); (b) the flushing of pesticides from a river/reservoir system; (c) the cooling process in a cup

of coffee (i.e. Newton's Law of Cooling); or (d) the influence of carbon emissions on global climate change.² What do we call this type of reasoning and why is it important?

The cognitive process on center stage here is the recognition of recurrent patterns of behaviors in different domains and situations. In the lists of systems thinking skills and habits, this skill tends to be assumed, but not frequently named. We're called to use this type of reasoning when we encounter natural or social systems that share certain characteristics or behaviors. We intuitively understand, for example, that competing street gangs

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Announcing the Educational Modeling Exchange

The Creative Learning Exchange (CLE) announces the establishment of the Educational Modeling Exchange (EME) to help nurture an active, collaborative, and growing

"community" of educators using system dynamics. Building on the CLE's successful outreach to a large and varied audience, the EME seeks

- 1) to refine and expand the size and scope of the CLE library of "exemplary" curricula and organizational programs,
- 2) to enhance teachers' and administrators' skills in applying existing materials (models, units, curricular materials) or in building and applying new ones,

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Updates...

Tucson

Our training sessions were very successful this year. We had a wait-list for our August training and actually had to turn people away. As of this summer, Borton Primary Magnet school now has 85% of their teaching staff trained (30 hours), and they have a full-time instructional coach (paid by the district) who will be helping us focus on systems thinking applications for teachers. Systems thinking has been designated as a focus for this K-12 magnet program. We figure that just about every child in the school will be immersed in systems thinking this year—how exciting! In addition, we have 2 other new schools that are purchasing STELLA and will be doing some modeling with students at the middle level. Lots going on in Tucson!

Tracy Benson <tsbenson@aol.com>

Exposé from Attune Group

Exposé is a new system dynamics modeling tool, developed to inter-connect Microsoft Excel with stock flow diagrams.

We have been thinking about conducting an experiment to evaluate the effectiveness of this tool in teaching mathematics (Differential/Difference equations, dynamic systems...) in high schools. Many students already know spreadsheets and we can use Exposé to build on what they already know toward systems thinking.

Here is my favorite example. I often use it to convey the value of Exposé as a tool that “builds on” what the students know vs. “forget everything and start over”:

Give a middle-school kid a pen and a piece of paper (and probably a calculator). Now ask him this question: If

EDITORIAL

This year looks as though it will be a busy and challenging one for the Creative Learning Exchange. We are especially excited about two big events this school year—the addition of the Educational Modeling Exchange to the CLE and the up-coming conference in June, 2006. Read about both ventures in this issue of the *Exchange*.

The Educational Modeling Exchange adds a whole new dimension of capability to the CLE. Jeff Potash and John Heinbokel are available to network, to help you solve your problems with curricula, to train, and to continue the process of making sure that the curricula available is meeting your needs as educators. They look forward to talking with you either through the K-12 list or directly. <heinbokelj@clexchange.org> and <potashj@clexchange.org>

The June conference this year is shaping up to be a stimulating and mind-stretching event, with many fascinating people to talk and interact with. Now is the time to start gathering school or grant funds to be able to join us at the Learning Center in Marlboro, MA. The Learning Center is Verizon's training facility, with everything from state of the art conference rooms to pool tables in the bar. We hope you can join us there!

Of special note is the well-deserved recognition of Jim and Faith Waters at the System Dynamics Society meeting this summer. They have been spectacular friends to system dynamics in K-12 education!

Have a productive and joy filled fall.

Take care,

Lees Stuntz <stuntzln@clexchange.org>

my savings in the beginning of January is \$1000 and I spend \$200 during the month of January, what would be my savings in the beginning of February? I would say there is, at least, a 99 percent chance that you would get the correct answer no matter how many times you repeat this experiment. Spreadsheet builds on this logic.

Now give another middle-school kid a SD software package and ask her the same question. What is the chance that you get the right answer? I tend to believe that it is pretty low, definitely lower than 99 percent. She has to identify the stock, then the flow and so forth, something she does not do, at least consciously, in her every day life. This is what I call structural logic. Although it could be quite rewarding in understanding the complexity of dynamic systems, structural logic is tough to apply.

What Exposé does is to bridge the gap between the two logics. Wouldn't it help to start with the numerical logic with spreadsheets and continue with structural logics? Exposé allows the students to work with both logics at any point in time. Students can do example one in a spreadsheet and see the stock-and-flow in Exposé, and use the modeling icons there to add other variables, such as interest.

I have been looking for entry points to high schools and resource to do small-scale experiments (larger scale experiments can be done with NSF grants). Any thoughts?

Mohammad Mojtahedzadeh

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and the advertising campaigns for Coke and Pepsi share a similar, underlying structural dynamic, i.e., escalation. When we are unaware of these dynamic structures, we are more likely to *react* to behaviors produced by them, rather than to understand and potentially take actions to *change* the structures. If we are able to see recurring dynamic structures around us, we begin, as Peter Senge suggests, in his book *The Fifth Discipline* (1990), “a process of freeing ourselves from previously unseen forces and ultimately mastering the ability to work with them and change them.” From an educator’s perspective, the ability to see similar patterns of behavior across disciplines translates into increased retention and transfer for students, as well as the potential for improved coherence across curriculum.

Sounds good, right? But what do we call this reasoning skill? And how does one develop it? This is where homologies and the use of homologous reasoning come in.³

Buckle your seatbelts for a moment as we take a brief ride into abstract space. I promise we will land on the ground in a paragraph or two.

In his theory of general systems, Viennese biologist Ludwig von Bertalanffy (1968) offered general principles that apply to systems, irrespective of their nature. Arguing for more precision in describing complex system phenomena, he suggested that analogies were of no help. In his own words, analogies are “superficial similarities of phenomena which correspond neither in their causal factors nor in their relevant laws.”⁴ Homologies, however, were particularly important “to describe formal correspondence between systems of any kind.” (p. 84)

Said more simply, where an *analogy* refers to a “correspondence in function” a *homology* is “a likeness in structure” (or pattern of interrelationships). Using an analogy, one might suggest that wolves/rabbits and lynx/

hares pairs are similar because they are all mammals; using a homology, one might note that these pairs are similar because they are part of predator-prey relationships.

We can think of homologous structures, such as coupled reinforcing and balancing feedback loops, as David Lane has suggested, “as 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.” Homologies can also be thought of as “explanatory schemas” that enable one to put one’s stock of knowledge into action. What is the advantage of such abstract schemas? As educational researcher Stellan Ohlsson explains, “content-full schemas, no matter how general, are limited to their respective domains, whereas an abstract schema is, in principle, transferable across domains (with what success is always an empirical question). This allows the formal thinker to think productively when faced with discourse from an unfamiliar domain.”⁵

Let’s have a bit of fun with this idea and imagine we overhear the following conversation:

As Schimogens’ appeal relies more on Wooser’s efforts, the emphasis given to Wooser’s efforts increases. This leads to more Wooser efforts and less effort given to developing new types of Schimogens. This further exacerbates the problem of the Schimogens’ poor overall performance.

What is this conversation about? Is this a conversation between two Jedi knights in the midst of an intergalactic battle? Perhaps, but we don’t need to know more about the Schimogens and Woosers to begin to understand the dynamics at play here. As we trace the changes over time and unintended consequences in this conversation, we might begin to recognize a common homologous pattern in which a fix—in this case, more

emphasis on the Wooser’s efforts—is doing more harm than good and is actually making the original problem worse. This homologous structure, or archetype, is often labeled “fixes that fail.”

Many researchers and practitioners have recognized that homologies, or structural similarities, exist within and among a variety of systems.⁶ These structures have been described in various literatures, and range from the almost folkloric “tragedy of the commons” to the more specific system dynamic “molecules.”⁷ For example, Jay Forrester, founder of the field of system dynamics, offers this example of homologous structures:

The dynamic structure that causes a pendulum to swing is the same as the core structure that causes employment and inventories to fluctuate in a product-distribution system and in economic business cycles. Humanities are taught without relating the dynamic sweep of history to similar behaviors on a shorter time scale that a student can experience in a week or a year.⁸

In alignment with Forrester are numerous psychologists, ecologists, scientists and other system dynamicists who have long argued that recognizing these similarities improves one’s ability to transfer problem solving insights from one context to another.⁹ Turning to K-12 education, Forrester has argued that the “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 behavior rest on the same kinds of dynamic structures.” Forrester provides this example:

A student in an eighth grade class grew bacteria in a culture dish, then looked at the same pattern of environmentally limited growth through computer simulation. From the computer, the student

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looked up and observed: "This is the world population problem, isn't it?" Such transfer of insights from one setting to another will help to break down barriers between disciplines. It means that learning in one field becomes applicable to other fields.¹⁰

How is homological reasoning being fostered in K-12 education today? Before we dive into this question, let us take a look at what is known about the development of this reasoning skill.

The Development of Homologous Reasoning

We know that adults, with advanced skills in the field of system dynamics, for instance, develop a mental library of recurring patterns of behavior and can recognize these generic structures¹¹ in widely different domains. Typically, this occurs over time, through graduate level classes and extensive research or client work.

Although there is a great deal of empirical research about the development of related skills, such as analogical reasoning,¹² there is not yet a cogent body of research on the development of homologous reasoning in children and adults. In a review of the analogical reasoning literature, I found that (a) analogical reasoning is considered an achievable skill for children as young as four¹³; (b) the development of analogical reasoning skills is influenced by the learning environment; (c) students make better analogies when they have more knowledge; and d) familiarity and practice with analogies facilitates students ability to reason by analogy.

...an integrated, interdisciplinary curriculum fosters students' abilities to recognize systems patterns in one domain and apply them in another.

This research has shown that children can progress from merely noticing the occurrence of analogies to productive use of analogies to solve prob-

lems.¹⁴ There is also a similar progression from focusing on surface similarities to a reliance on deeper structural analogies. For example, during their three-year research effort to develop a "community of learners" among fifth and sixth grade students and their teachers, educational researchers Anne Brown and Joseph Campione found that "children initially make surface analogies, such as between human eyes and the headlights of a car (surface), while later they make the analogy between a car's engine and the human heart (deep)." Brown and Campione found that increased knowledge in and across domains facilitates a child's shift from accepting "superficial analogy" to using "deep analogy" to explain behaviors and mechanisms. As Brown and Campione explain:

Although in the laboratory, this development from noticing to using, and from surface to deep, was thought to be age-dependent, the classroom work suggests that the shift is knowledge-based, occurring micro-genetically within a year as readily as cross-sectionally across several years.¹⁵

This finding provides strong support for something many systems educators already know: an integrated, interdisciplinary curriculum fosters students' abilities to recognize systems patterns in one domain and apply them in another.

As part of the studies conducted by Brown and Campione, they also found that "practice creates a mind-set to reason by analogy" (p. 250). This finding is supported by several action research projects conducted by members of the Waters Foundation. In one such project, an interdisciplinary team* of teachers and Waters Foundation mentors wanted to know if the use of systems thinking skills would facilitate the ability of 7th

grade students to see similarities between different systems. Specifically, they

asked whether students would be able to recognize and transfer the generic structure of exponential growth in scenarios involving a bank account, Fibonacci rabbits, world population and bacterial populations.

In math class, students used a model called Fibonacci Rabbits. In science class, students grew bacteria and used a model of bacterial growth in the context of potato salad spoiling at a school picnic. In social studies class, students used a computer model that simulated world population growth and the dependence on oil for energy. During the course of these activities, students were also exposed to other exponential patterns (a bank account and the *One Grain of Rice* story) in a series of lessons in computer technology class. It was in this context that time was afforded for practice of homologous reasoning. According to Larry Weathers, "we read (in the learning transfer literature) that students would not significantly develop the skills of picking up transfer of knowledge to other situations unless they had the exposure to the process and the opportunity to practice it in a guided way."

How well did the students do? According to the team report: "Students improved in their ability to anticipate the feedback relationship that caused the exponential growth pattern and to successfully explain it. The percent of students receiving the highest rubric grade when asked to explain the cause of the exponential growth pattern improved from 13% of students to 55%. Students also improved in their ability to come up with an example of exponential growth from prior experience, with 38% of students answering this question in the pre-test compared to 61% of students in the post test."

In my own doctoral research, I investigated middle school students'

* This team included Scott Hoffman, Barbara Bowden, Mike Desarro, Robin Goldstein, Dick Maki and Larry Weathers of the Bromfield School, Harvard, Massachusetts.

and their teachers' naïve conceptions of dynamic systems. As part of this study, participants provided their intuitive understanding of six systemic scenarios (involving predator-prey relationships, birth rate and population trends, room clean-up dynamics, and so on), and were then asked to describe a similar situa-

When students are asked to make connections between what they are reading and/or studying and their own lives, their engagement increases, along with the quality of their oral and written explanations.

tion, but from a different domain. For example, after describing how wolves and rabbits are interrelated, participants were then asked to describe another situation that seemed similar, but was not an example from the animal kingdom. Without previous formal experience with generic systems structures, a surprising number of students (21%) and teachers (53%) described homologies that were structurally similar yet distinct in terms of the domain.

Here is a sample response from a student I will call "Toby." When asked to think of a similar situation to the wolf-rabbit story he just told, Toby responded:

There's something sort of like that with environmentalists. When there's really low enough attention paid to the environment that they're supporting, then they just get frantic. It boosts the numbers of people, then they get more secure. Then once the area they're concentrating on is back to around normal, they just ignore it, and slowly the numbers just go down until it's back to, "oh my God!" They wait until the last possible minute to react. And it goes on like that.

A Waters Foundation action research project with middle level schools in Tucson surfaced similar homologous reasoning skills by middle school students. Here, Tracy Benson, a Waters Foundation mentor, shares this student-generated example of a "Fixes that Fail" archetype:

My Mom nags me to clean my room, I stuff things in my closet and under the bed (quick fix), and at first she doesn't see it, but then I get her even more mad when she discovers that I still have a mess, even though it is kind of hidden. In addition, it ends up taking me more time in the long run to clean because I have to pull everything out from

hiding and put things in their right places. This is also like the problem I have when I have a test or big paper due. I sometimes decide to copy or cheat and sometimes I get away with it. But sometimes the teacher finds out, and I have to rewrite or do extra credit because I get zeros. It then takes me even more time to do homework or study. It is reminds me of when I went to a new school and wanted to make friends. I tried acting "cool" and not like myself (quick fix). I ended up getting attention from the wrong crowd, which prevented me from making friends who were more like the ones I had at my old house.

How is this similar to that? Fostering a habit of mind

Educators, organizational leaders, and academics alike will attest that developing a mental stock of generic structures can be a powerful means of accelerating learning and generating insight in people of any age. How do we help young people to become aware of these recurring structures in our personal and professional lives?

Use systems archetypes as thought organizers

Educators and parents can create opportunities for familiarity and practice, just as the Waters Foundation team did with the group of seventh grade students in Harvard, Massachusetts. A means of raising awareness of homologous structures is to use the systems archetypes as "thought organizers." In several Tucson schools, systems archetypes such as "Fixes that Fail," "Escalation,"

"Shifting the Burden," and "Tragedy of the Commons"¹⁶ are commonly used by reading, writing, and social studies teachers, at the middle level primarily, but also in a kindergarten through second grade school whose teachers use systems archetypes with reading comprehension. Students use the archetypes to organize their thoughts prior to writing to help them compose dynamic, fluent stories or expository essays. According to Tracy Benson, "Two different action research projects this year gleaned the motivational pay-off of using archetypes with students. When students are asked to make connections between what they are reading and/or studying and their own lives, their engagement increases, along with the quality of their oral and written explanations."

Making the link to curriculum standards

It is useful, perhaps even critical in some school settings, to know how homologous reasoning aligns with the state's curriculum standards. Generally, homologous reasoning is most closely aligned with "Complex Thinking Standards," one of five dimensions of learning linked to assessment standards. Marazano and colleagues¹⁷ identify thirteen of the most commonly recognized complex reasoning skills (p. 19):

- Comparing
- Classifying
- Induction
- Deduction
- Error Analysis
- Constructing support
- Abstracting
- Analyzing Perspectives
- Decision Making
- Investigation
- Experimental Inquiry
- Problem Solving
- Invention

To meet the "Complex Thinking Standards," students must be able to effectively use the above complex reasoning strategies. Homologous reasoning

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is aligned with several of the strategies listed above, including “abstracting.” Abstracting is defined as: “Identifying and explaining how the abstract pattern in one situation or set of information is similar to or different from the abstract pattern in another situation or set of information” (p. 74). Questions related to abstracting include: “What’s the general pattern of information here? Where else does this apply? How can the information be represented in another way, for example, graphically or symbolically?”

Look for opportunities within and across current curriculum units

When teachers and school administrators value homologous reasoning as a necessary skill, teachers are encouraged to look outside their own disciplines and to see interconnections between such topics as math and humanities. Teachers may also be drawn to co-teaching subjects in the same room. However, our current educational climate, with its emphasis on the disciplines and standardized tests, may not allow for such interdisciplinary teaching.

Another opportunity then lies within the middle school and high school curricula. A good example of this is a series of curriculum modules designed by Harvard’s Tina Grotzer and colleagues

to infuse models of causality into topics such as pressure, electrical circuits and ecosystems.¹⁸ Grotzer argues that understanding about ecosystems, for example, involves reasoning about forms of causality that are unfamiliar to many students. Using the ecosystem module, teachers infuse models of causality found in ecosystem units to deepen students’ understanding. For example, students are taught to understand the inherent temporal delays in decaying processes and the importance of “balance and flux” processes in ecosystem populations through case studies, self-generated causal maps and StarLogo models. By asking cross-domain questions such as, “How are these dynamics similar to situations you see at home, at school or in the newspaper?” teachers may foster students’ homological reasoning skills as well. In this way, students learn important disciplinary knowledge but are also encouraged to detect interrelationships and dynamics across disciplines as well. As educators and parents alike, we can make stronger links between the disciplines (multi-disciplinary study) and across disciplinary subjects (interdisciplinary study). Issues such as hunger and climate change are matters not only of science, or geography, or economics, or philosophy. They cut across several disciplines and are understood only to the extent that these domains are addressed together.¹⁹

Asking different questions

Finally, one simple way parents and educators can help young people become aware of recurring dynamic structures is by asking different questions. As young people encounter a particular challenging or chronic situation, parents and educators can help the young person to pause before leaping to a conclusion, and instead ask questions such as: “What happens next?” or “Where else have you seen, or, might you, see this pattern?” or “How is this situa-

tion like that?” I offer here an anecdote from my own parenting experience. Not long ago I read the following tale of Hercules and Pallas (one of Aesop’s Fables) to my sons:

Hercules, once journeying along a narrow roadway, came across a strange-looking animal that reared its head and threatened him. Nothing daunted, the hero gave him a few lusty blows with his club, and thought to have gone on his way. The monster, however, much to the astonishment of Hercules, was now three times as big as it was before, and of a still more threatening aspect. He thereupon redoubled his blows and laid about him fast and furiously; but the harder and quicker the strokes of the club, the bigger and more frightful grew the monster, and now completely filled up the road. Pallas then appeared upon the scene. “Stop, Hercules,” said she. “Cease your blows. The monster’s name is Strife. Let it alone, and it will soon become as little as it was at first.”

The moral? “Strife feeds on conflict.”

After the story, I asked my son where else he saw this same kind of situation. Sheepishly, he pointed to his brother. He then went on to explain how sometimes one tease leads to a poke, which leads to a push, and so on. (You know the scenario.) In my son’s explanation, I heard the dynamic of escalation. One party does something that is seen as a threat by another party so the other party responds in kind, increasing the threat to the first party. This results in even more threatening actions by the first party and the cycle continues.

I then asked what I think of as the “policy level” question: What could you do differently? My son suggested that walking away and leaving his brother alone for a while would work. I thought so too.²⁰

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In Closing

Thanks to the many educators, practitioners and academics within and around the system dynamics community, we have seen that fostering homologous reasoning has many potential benefits. These include:

- *Increased student engagement.* As students are encouraged to make connections between what they are reading and/or studying and their own lives, they become more engaged and personally involved in what they are learning.
- *Improved transfer and problem solving skills.* Academic researchers have long argued that recognizing similarities improves one's ability to transfer problem solving insights from one context to another. The experience of systems educators is showing that knowledge of underlying structural similarities can enable students of any age to think productively when faced with unfamiliar terminology or scenarios.
- *Increased retention.* In one of his many penetrating insights, educational researcher Jerome Bruner observed that human memory is greatly facilitated when “detail is placed in a structured pattern.” Without a structured pattern, Bruner argued, “detail is rapidly forgotten.” Encouraging homologous reasoning in students can improve retention and transfer of materials by helping students access and refine schemas of the concepts they need to acquire.
- *Increased student empowerment.* The ability to recognize patterns of behavior within what may appear to be what Russ Ackoff has called a “wicked mess” is empowering. Armed with this understanding, young people have a greater ability to analyze and act in informed ways without jumping to blame a single cause for the challenges they will encounter.

- *Improved coherence across the curriculum.* Emphasis on homologies can also create a bridge between and among disciplines, for example, between science and the humanities, and so improves coherence across curricular units.

There is no one pedagogy, book or computer program that will help students develop homologous reasoning skills. Instead, we must take every opportunity – scanning our everyday artifacts such as newspapers, text books, games, museum displays and the media – to help our young people develop habit of mind that looks across disciplines and appreciates similar system dynamics. With consistent efforts to develop homologous reasoning – as of yet seen as an unusual, even revolutionary way of thinking – we may see it transform into what Art Costa has called natural habit of mind. As Toulmin and Goodfield²¹ once observed: “One century's common sense is an earlier century's revolutionary discovery that has since been absorbed into the natural habits of thought.”

Endnotes

¹ The rain barrel represents a stock/flow structure: the amount of water in the barrel is the “stock”; the water flowing into and out of the barrel are “flows.” At the core of system dynamics lies the premise that the structure of a system (comprised of, for example, stock/flow relationships and feedback loops) generates the behaviors we observe over time. In any stock/flow structure—whether it be the national debt (stock) and the national deficit (flow), or the number of trees (stock) and the rate of harvesting/planting (flows)—when the inflow into a stock is greater than the outflow, the level of the stock is rising. When the outflow is greater than the inflow, the level of the stock is falling. When the inflow is equal to the outflow, the level of the stock remains steady.

² In global climate change, for example, we can imagine the concentration of greenhouse gases (GHG's) as a bathtub or stock. Flowing from the faucet into the stock of GHG's are human-generated GHG emissions. The drain or flow out of the bathtub is the rate at which CO₂ is

removed from the atmosphere (via net uptake by biomass, the ocean, and other sinks). Most climatologists agree that due to deforestation and saturation of other carbon sinks, human GHG emissions are almost twice the rate of removal. The bathtub is filling twice as fast as it is draining.

³ In my own doctoral research, I've come to call this process *homologous reasoning*. I choose “homologous reasoning” here over “archetypal reasoning” because of its specificity regarding underlying structures, its inclusiveness of generic causal patterns (represented by influence diagrams, causal loop diagrams or stock/flow diagrams) and its closer connection to the cognitive science and human development literatures/communities.

⁴ Homologies as a concept can be traced back to Aristotle but the term was first coined in 1843 by anatomist Richard Owen. For Ludwig Von Bertalanffy's view of homologies, see his book *General System Theory: Foundations, Development, Applications* (1968).

⁵ For more on “abstract schemas” see Ohlsson's article in the journal *Educational Psychologist*, (1993), volume 28.

⁶ The list of those who have described structural similarities within physical, biological, economic and social systems is of course too long to include here. Some of those works that have most influenced my own thinking include: W.B. Cannon's *The Wisdom of the Body* (1939), Jay Forrester's *Counterintuitive Behavior of Social Systems* (1971), Gregory Bateson's *Steps to an Ecology of Mind* (1972), Donella Meadows' *Whole Earth Models & Systems* (1982). Peter Senge's *The Fifth Discipline* (1990), Daniel Kim's *Systems Archetypes I* (1992) and David Lane and C. Smart's 1996 article in the System Dynamics Review: *Reinterpreting Generic Structure: evolution, application and limitations of a concept*.

⁷ In a 1968 issue of *Science* magazine, Garrett Hardin first described “Tragedy of the Commons” in this way: “Much of man's world is treated as a ‘commons’ wherein individuals have the right to freely consume its resources and return their wastes. The ‘logic of the commons’ ultimately produces its ruin as well as the demise of those who depend upon

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it for survival" (volume 62, p. 1243). For more on systemic "molecules", see Hines, J., Eberlein, B., Richardson, G., Johnson, D., Richmond, B., & Melhuish, J. (1996-2000). *Modeling with Molecules 1.4* (Version 1.4) [Vensim]. Harvard, MA.: LeapTec and Ventana Systems, Inc.

⁸ This quotation is drawn from Jay Forrester's 1992 talk, *System Dynamics and Learner-Centered-Learning in Kindergarten through 12th Grade Education*—a highly recommended read. The full text can be found on the CLE website (see: www.clexchange.org).

⁹ Particularly strong arguments related to the link between recognizing structural similarities and improved transferability of problem solving insights have been made by Robert Nisbett, G. Fong et al. (see their 1987 article: "Teaching Reasoning" in *Science* (238, 625-631) and Jim Doyle (see his 1997 article: "The Cognitive Psychology of Systems Thinking," *System Dynamics Review*).

¹⁰ Forrester, J. (1992). *System Dynamics and Learner-Centered-Learning in, Kindergarten through 12th Grade Education*. Acton, Massachusetts: Creative Learning Exchange (www.clexchange.org)

¹¹ Other terms one might hear used for generic structures (a term coined by Mark Paich) include "systems archetypes" and "kernel structures" (a term used by Dennis Meadows).

¹² Analogical reasoning research has explored people's ability to recognize either superficial or deep structural similarities in a well-known domain and apply it to another domain. However, very few studies discuss children's and adult's ability to recognize homologous structures across natural and social systems. Several studies do look at children's or adult's ability to recognize and utilize homologous structures within the same domain (for example, within ecosystems or within management-related systems). For a review of the analogical reasoning literature as it relates to the development of systems thinking skills in general, see "Thinking about everyday systems: An empirical investigation of middle school students' and their teachers' understanding of natural and social systems" (2004), Harvard Graduate School of Education, unpublished manuscript.

¹³ I have heard numerous examples of children as young as four or five demonstrate rudimentary homologous reasoning skills. Here is a brief example from my own personal experience:

While driving around a crowded rotary with my two sons, my then four-year old noticed the congested traffic ahead. People in cars and trucks were honking impatiently as they tried to navigate their way through the orange cones set up by a road construction crew. Pointing to the cars darting in and out, my son asked, "Mommy, what happens when everyone says 'me first'?"

Humbled by the wisdom of his simple question, I responded, "What do you think would happen if everyone said 'me first'?"

He suggested there might be a few accidents or even "a big, huge crash!"

I then asked, "Are there other situations you can think of when everyone says 'me first'?"

To my great surprise (and delight) he responded, "Mommy, you know how you said it's not good to let the water run when we brush our teeth because if everyone did that the reservoir would go down? Well, it's kinda like that."

At his tender age, he was making the connection to the "tragedy of the commons" archetype, a common pattern of behavior that emerges around the "commons"—e.g., over-crowded community pools, over-used water supplies, and so on.

¹⁴ Much of this research has been conducted by Diedre Gentner. I found Gentner and Stevens' *Mental Models* book (1983, Lawrence Erlbaum) to be particularly helpful.

¹⁵ For the complete study, see: Brown, A., & Campione, J. (1994). Guided Discovery in a Community of Learners. In K. McGilley (Ed.), *Classroom lessons: Integrating cognitive theory and classroom practice*. Cambridge, MA: MIT Press.

¹⁶ Kim, D. (1992). *Systems Archetypes I*. Waltham, Massachusetts: Pegasus Communications (www.pegasuscom.com)

¹⁷ See Marzano, R. J., Pickering, D. J., & McTighe, J. (1993). *Assessing Student Outcomes: Performance Assessment Using the Dimensions of Learning Model*.

Alexandria, Virginia: Association for Supervision and Curriculum Development.

¹⁸ The curriculum module—*Causal Patterns Ecosystems: Lessons to Infuse into Ecosystems Units to Enable Deeper Understanding*—was created by Tina Grotzer and colleagues K. Donis, D. MacGillvray, S. Mittlefehldt, R. Lincoln and R. Gould (2003). It is available on-line through the Project Zero website (www.pz.harvard.edu/).

¹⁹ When should we begin to teach our students to recognize, understand, and ultimately to affect these systems? I have been personally astounded by glimpses of systemic reasoning in three- to four-year-olds and so, resonate with Bruner, when he observes in *The Process of Education* (1960/1977) "any subject can be taught to any child at any age in some form that is honest."

²⁰ This anecdote also points to the potential of children's stories as a means of fostering homologous reasoning skills. For a sampling of such "systemic" stories, see *When A Butterfly Sneezes: A Guide for Helping Children Explore Interconnections in Our World Through Favorite Stories* (2001, Pegasus Communications). Additional stories can be found on the Waters Foundation website. (See www.watersfoundation.org; click on "literature connections.")

²¹ Toulmin, S., & Goodfield, J. (1961). *The Fabric of the Heavens*. London: Hutchinson.

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This article is available on the CLE website <clexchange.org> listed as How is This Similar to That? under Implementation.

Recognition of Jim and Faith Waters

Presented by George Richardson at the System Dynamics Conference Boston, Massachusetts, July 20, 2005

We honor today Jim and Faith Waters for a special kind of contribution. It's not for research, at least in the traditional sense, nor for excellence in consulting applications, at least as we usually think about those in system dynamics, nor for path-breaking articles written for the system dynamics community or our larger audiences. The contributions of Jim and Faith Waters could be said to be even more fundamental than those: they have provided crucial, trusting, insightful support for developing systems thinking and system dynamics in elementary and secondary education. Their contributions have helped to place lasting systems intuitions, insights, and habits of thought in thousands of young people.

Those closest to this work estimate that the contributions of the Waters have directly or indirectly touched at least 82,000 young students. Some twenty five schools in the United States have been actively supported, each for an average of eight years. Teachers from another eighty schools took part in workshops, training, and site visits and profited from materials developed. Multiply by the number of students per teacher and you begin to see the profound effect. Add in the hits to the Waters Foundation web site, one-time workshops and presentations at conferences made possible by Waters's support, and the number quickly balloons above 100,000 or even 200,000 young people exposed to systems insights and habits of thought because of what Jim and Faith are doing.

To these thousands of students and their teachers, the contributions of the Waters brought

- teacher training by great system dynamics practitioners and systems thinking teachers,
- long-term mentoring by gifted and

committed systems educators,

- a growing pool of resource materials including library resources to support teaching efforts from kindergarten to high school,
- equipment like mobile computer laptop labs that helped many teachers experiment with dynamic modeling and helped the Waters group learn about the effective uses of models and modeling in the classroom,
- documentation, including support for time, materials, and services for writing and editing and for creating, updating, and maintaining the web site,
- and dissemination, so that hundreds, even thousands of teachers can benefit from lessons, explanations, guidelines, and the like that emerge from the work and are provided on the Waters Foundation web site and in a variety of publications.

But the contributions of the Waters are measured not just by the quantities of schools and teachers and students influenced, or the equipment provided or the sheer number of lessons edited and disseminated. They brought their own wisdom to the effort and delivered it all with a style and grace that had a deep influence on all the educators who were privileged to work with them. Here's what some of those most directly connected with the work have to say:

"The greatest gift we received from the Waters was their trust. ... They have consistently given us permission to do what we believe is best for students.

"Jim and Faith have modeled and encouraged collaboration both within the K-12 community and between the K-12 community and the worlds of business, government, and higher education. Never in my experience has such a diverse network of folks sustained communication and collaboration for such a long period of time.

"The Waters both remind us consistently that we don't really know the 'right way' to do this – we're creating and refining a new area of pedagogy – a combination of K-12 research-based practice, systems thinking, and our own experience and intuition about learning.

"Jim and Faith gave us the license and the encouragement to take the risk to do something new but also the reminder to consistently test our theories."

Another says:

"The guidance Jim and Faith have given us includes their famous 'words of wisdom,' which will forever be a part of my life as a learner. Some examples:

'Only go with moving trains,' meaning those teachers who demonstrate efforts to learn and build systems thinking capacity. Jim further would warn us 'to not try to get the trains out of the station,' explaining that the effort to get disinterested people involved may just be fruitless.

'Remember the last inch.' Jim and Faith emphasize the importance of finishing up aspects of projects and not leave unfinished business hanging. This 'last inch' reminder is especially helpful as the work pulls us in numerous exciting directions and generates other promising but distracting great ideas and projects."

And yet another offers these words:

"One point I always make to people who don't know Jim and Faith is what a wonderful combination of scientific thinking, entrepreneurial spirit, and teacher sensibility the two of them embody as a couple. From my point of view as a K-12 educator who advocates inclusion of systems thinking and dynamic modeling in our students' education, I can't imagine interacting with two people

Jim and Faith Waters continued on page 10

15th Annual Pegasus Conference November 14-16, 2005

15th Annual Pegasus Conference Systems Thinking in Action® *Embracing Interdependence: Effective and Responsible Action in Our Organizations and the World* San Francisco, California November 14–16, 2005

Interdependence binds us together in a single destiny, yet we aren't always aware of the web of connections that shapes our world. As we gain understanding of the systems we are a part of, we become both more effective in responding to challenges and more accountable to

others for the current and future results of our choices. At this year's event, we will engage in methods that contribute to the accomplishment of our mutual goals in an increasingly interdependent world.

This year's keynote presenters include:

Peter Senge--The author of the widely acclaimed book, *The Fifth Discipline*, and founding chair of the Society for Organizational Learning, Peter has played a pivotal role in shaping the organizational learning field.

Rose von Thater-Braan (Tuscarora/Cherokee)--Cofounder of the Native

American Academy, a network engaged in the study of Native science, Rose served as the director of education at UC Berkeley's Center for Particle Astrophysics for 11 years.

Leroy Little Bear--A member of the Small Robes Band of the Blood Indian Tribe of the Blackfoot Confederacy, Leroy has a J.D. from the University of Utah. He was a professor in the Native American Studies Department at the University of Lethbridge and director of the Harvard University Native American Program.

Marv Adams--As senior vice president, Ford Motor Company, and chief information officer, Marv is leading Ford's effort to develop the capability to rapidly sense and respond to marketplace changes.

Mary Catherine Bateson--A writer, educator, and cultural anthropologist, Mary Catherine is engaged in exploring changing patterns of communication among the generations and the implications for how we build the future together.

Daniel H. Kim--A renowned thinker, author, and speaker in the fields of systems thinking and organizational learning, Daniel is committed to helping problem-solving (reactive) organizations transform into problem-dissolving (generative) organizations.

Special Subscriber Price!

Subscribers to the *CLExchange* can register for the conference for \$995—a \$600 savings off the regular price of \$1595.00—through October 28, 2005. Simply use Priority Code CLE2005 when you place your order. To register or learn more about the conference, visit www.pegasuscom.com/stapage.html, call 1-781-398-9700, or e-mail to carrier@pegasuscom.com.

Download a copy of the conference brochure at <http://www.pegasuscom.com/pc05/pc05brochure2.pdf>.

Jim and Faith Waters continued from page 9

whose life experience—past, present, and future—could serve as a better example to me of asking tough questions, energetically searching for answers, and inviting students and fellow educators to 'ask and search' as well."

This "action research" that Jim and Faith urged throughout tells us that the efforts are working. We know that students are using systems tools to make their thinking visible, and we know for sure that that process improves their thinking. We know for sure that systems thinking tools help young people (as well as us) make connections and see similarities of structure in disparate contexts (think of rumors and infections). We know that students exposed to systems thinking and modeling approach problems differently, often challenging obvious solutions to complex problems.

We know that they grow to reflect critically on their own thinking. We know that systems thinking tools and habits of thought help young people to read more critically and with more recall, and to write better and with more facility. And we know that in using systems thinking concepts and tools, many students show increased motivation, engagement, and self-esteem from realizing the power of their system thoughts. That increased engagement may be the most dramatic and important of all the effects: motivated, engaged kids can do almost anything.

Jim and Faith Waters have helped to grow these wonderful things, and they have done it in inspiring ways. For these contributions the System Dynamics Society is pleased to honor them with this special recognition.

The plaque reads:

**Special Recognition
of the contributions of
JIM and FAITH WATERS
for
Unwavering Vision, Guidance, and Support
of Systems Thinking and System Dynamics
in Elementary and Secondary Education**

**System Dynamics Society
2005**

Educational Modeling Exchange continued from page 1

3) to utilize existing and newly created networks to pursue new funding for more ambitious goals.

With start-up support from Allen Boorstein, of Amber Blocks, and Jay Forrester, of MIT, the Educational Modeling Exchange will be co-directed by Drs. John Heinbokel and Jeff Potash, whose names should be familiar to many readers of the *CLEExchange*. They are educators with over three decades of combined experience using system dynamics in developing software (MSST and Demo Dozen), designing and offering workshops and other training opportunities for teachers and administrators, and experimenting with interdisciplinary curricular applications with and for middle-school, high-school, and college students (focusing on such disparate topics as the impact of disease on human history, sustainability, population and food dynamics, and personal finance). This "academic odd-couple" (oceanographer and religious historian) brings a wealth of

ideas for pursuing new research, supporting enhanced networking, and providing "service" to meet the needs of a growing and evolving educational community.

Much of Jeff's and John's focus in the immediate future will be on identifying opportunities for current educational practitioners to enhance and apply their personal skills, and to leverage those efforts to strengthen and expand the application of system dynamics in education. They will be describing those efforts in future editions of the newsletter and on the K-12 listserv.

Jeff and John welcome the opportunity to discuss any modeling questions or ideas for enhancing our shared vision for a vibrant and growing community of educators using system dynamics.

"There is very little we can "DO" on our own in the EME; expect that we will contact you to solicit ideas, feedback,

and assistance on the initiatives we'll be exploring and pursuing." (from Jeff and John)

You can contact them through the CLE: heinbokelj@cleexchange.org or potashj@cleexchange.org or just ask a question on the list (k-12sd@sysdyn.cleexchange.org).

One on One with Dennis Meadows: Growth on a Finite Planet

by Pegasus Communications

What will happen when we outgrow the planet? More than 30 years ago, system dynamicist Dennis Meadows and his team began to examine the consequences of growth on a finite planet, using an understanding of complex systems, sophisticated computer modeling, and timely data. Their projections were sobering: given the world's ever-increasing appetites, the same pattern of growth that had brought a century of progress could eventually lead to a period of dramatic reversal.

In this eye-opening vision of possible futures, Meadows spells out the dangers, examines the ways of thinking that have led to this critical point, and offers direction to those who are ready to become part of the solution. The clear explanations of the dynamics of growth and sustainable development make the video a unique resource for classrooms and for nonprofit organizations with a focus on sustainability.

Special Subscriber Price!

Subscribers to the CLEExchange can order the video for \$125.00—almost 30% off the regular price of \$175.00—through October 28, 2005. Simply use Priority Code CLE2005 when you place your order. To order or view clips of the video, visit <http://www.pegasuscom.com/m2/media.html>, call 1-800-272-0945, or e-mail to info@pegasuscom.com.

Back by Popular Demand – "Stories of the Month" by Barry Richmond

Since Barry Richmond created the first "Story of the Month" in May, 2001, dates have changed, but the issues addressed are still relevant. Using systems thinking and the storytelling capabilities of the *iThink* and *STELLA* software, these stories stimulate discussion about topics that continue to plague our headline news.

Select titles include:

- Can Energy Prices Really Be Passed on to the Consumer?
- Guns at School
- Systems Thinking Look at Terrorism
- Reforming "School Reform"
- Hot Air & Greenhouse Gases

And more...

Enjoy reading these Systems Thinking classics! To learn more, visit www.iseesystems.com/SOTM or email us at info@iseesystems.com.

Systems Thinking and Dynamic Modeling: A Conference for K-12 Education

The Learning Center, Marlboro, Massachusetts
June 24-26, 2006

Join some of the finest system dynamics practitioners in a learning bonanza designed to foster systemic change and community-building in K-12 education:

- Explore your ideas about how schools need to change to meet the needs of today's students and their communities with Peter Senge, author of *The Fifth Discipline*.
- Learn from John Sterman why system dynamics is necessary for you, your students and your school.
- Learn how to teach systems through game-playing with Dennis Meadows and Linda Booth Sweeney, authors of *The Systems Thinking Playbook*.
- Talk with Jay Forrester, founder of the field of system dynamics, about lessons learned in 50 years of system dynamics.

- Expand your knowledge of system dynamics with George Richardson of SUNY Albany and Jim Lyneis of WPI.
- Learn how to address the critical thinking needs of your students with a broad palette of systems thinking tools and modeling techniques from the authors of *The Shape of Change*, *Modeling Dynamic Systems: Lessons for a First Course*, and many other experienced K-12 professionals.

This year's conference has been designed to maximize your learning, provide take-away practical knowledge, and bolster opportunities to meet and network with others. It will center around:

- Workshops with hands-on learning
- Informative plenary presentations
- Discussion roundtables

- Ample opportunities for less formal networking and schmoozing

The offerings will range from Introductory to "Master Class," and will focus on curricula, classroom management, and organizational themes to meet participants' needs for addressing specific grade levels, systems tools, and disciplines.

The conference cost per person is \$455.00. Discounts will be given for groups and presenters.

Please mark your calendars, and recruit colleagues across grades, disciplines, and organizational roles to make an effective team. Keep an eye on the CLE website and subsequent issues of this Newsletter for further details.

INTERESTED IN INVESTING?

If you would like to invest in our effort here at *The Creative Learning Exchange*, your contribution would be appreciated. You may donate any amount you wish; perhaps \$50.00 is a reasonable amount for a year. All contributions are tax-deductible.

Enclosed is _____ to *The Creative Learning Exchange* to help invest in the future of K-12 systems education.

Name _____

Address _____

e-mail _____

Thank you!

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The Creative Learning Exchange is a trust devoted to encouraging exchanges to help people to learn through discovery. It is a non-profit educational institution and all contributions to it are tax deductible.