FEATURE

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HOW IS THIS SIMILAR TO THAT?

BY LINDA BOOTH SWEENEY

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* 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. 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 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."

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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 the 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.

The Power of Homologies

In his theory of general systems, Viennese biologist Ludwig von Bertalanffy offered general principles that apply to systems, irrespective of their nature (the following quotations are from his 1968 book, *General System Theory: Foundations, Development, Applications*). 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." Homologies, however, were particularly important "to describe formal correspondence between systems of any kind."

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.

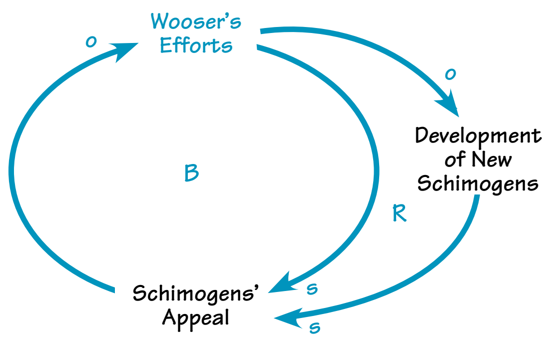
We can think of homologous structures, such as coupled reinforcing and balancing feedback loops, as devices that help us look beyond the obvious. As David Lane has suggested, homologous structures "seek to provoke the user into thinking in certain loose categories and comparing real world phenomena with 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."

Structural Similarities

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 empha-

DYNAMICS AT PLAY



We don't need to know anything about Schimogens and Woosers to begin to understand the dynamics at play here. The changes over time and unintended consequences represent a common homologous pattern in which a fix—in this case, more emphasis on Wooser's efforts—actually makes the original problem worse. This homologous structure, or archetype, is often labeled "Fixes That Fail."

sis 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" (see "Dynamics at Play").

What is this conversation about? Is this 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. 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." 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." (This and the quotations below are drawn from Forrester's 1992 talk, *System Dynamics and Learner-Centered-Learning in Kindergarten through 12th Grade Education*, available at www.clexchange.org.)

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. 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." He 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 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."

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 structures 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, there is not yet a cogent body of research on the development of homologous reasoning. A review of the analogical reasoning literature shows that (a) analogical reasoning is considered an achievable skill for children as young as four; (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.

This research has shown that children can progress from merely noticing the occurrence of analogies to the productive use of analogies to solve problems. 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 they explain:

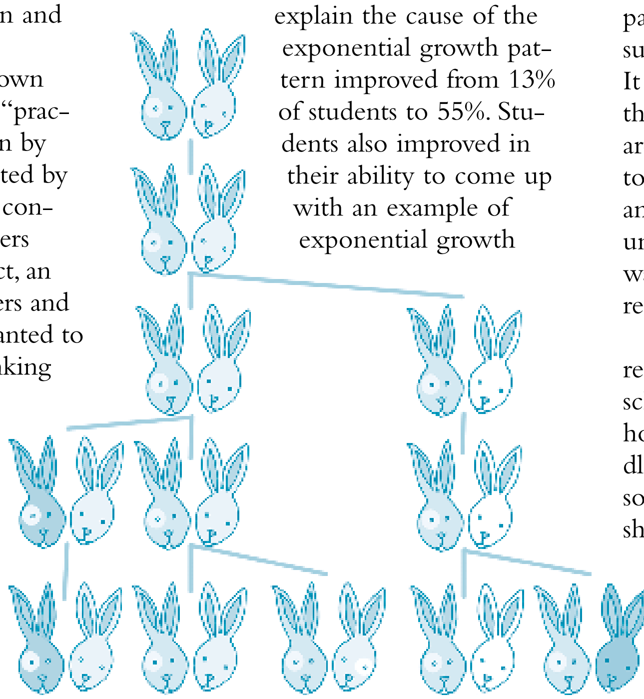
“Although in the laboratory, this development from noticing to using, and from surface to deep, was thought to be age-dependent, the classroom work suggests that the shift is knowledge-based, occurring micro-genetically within a year as readily as cross-sectionally across several years.” (For the complete study, see Brown and Campione, “Guided Discovery in a Community of Learners,” in *Classroom Lessons: Integrating Cognitive Theory and Classroom Practice*, edited by K. McGilley.)

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 their studies, Brown and Campione also found that “practice creates a mind-set to reason by analogy.” 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 seventh-grade students’ ability 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. Larry Weathers, a Waters Foundation mentor, explains: “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’ 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 situation, 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 instruction related to 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, 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 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."

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. 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" 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. In *Assessing Student Outcomes: Performance Assessment Using the Dimensions of Learning Model* (1993), Marazano and colleagues identify 13 of the most commonly recognized complex reasoning skills:

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

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.

To meet the "Complex Thinking Standards," students must be able to effectively use the above complex reasoning strategies. Homologous reasoning 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." 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 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 (see *Causal Patterns Ecosystems: Lessons to Infuse into Ecosystems Units to Enable Deeper Understanding* at www.pz.harvard.edu/). 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 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 (multidisciplinary 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.

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 situation like that?" I offer here an anecdote from my own parenting experience as an example. 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 older son where else he had seen this same kind of situation. Sheepishly, he pointed to his little 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 might work. I thought so, too.

Many Meaningful Benefits

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 domain 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 improve 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, textbooks, games, museum displays, and the media—to help our young people develop habits of mind that look across disciplines and appreciate 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 a "natural habit of mind." As Toulmin and Goodfield once observed in *The Fabric of the Heavens* (1961): "One century's common sense is an earlier century's revolutionary discovery that has since been absorbed into the natural habits of thought." ◘

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A version of this article that includes extensive references and notes is available on the Creative Learning Exchange web site (www.clexchange.org) in the Fall 2005 newsletter.

