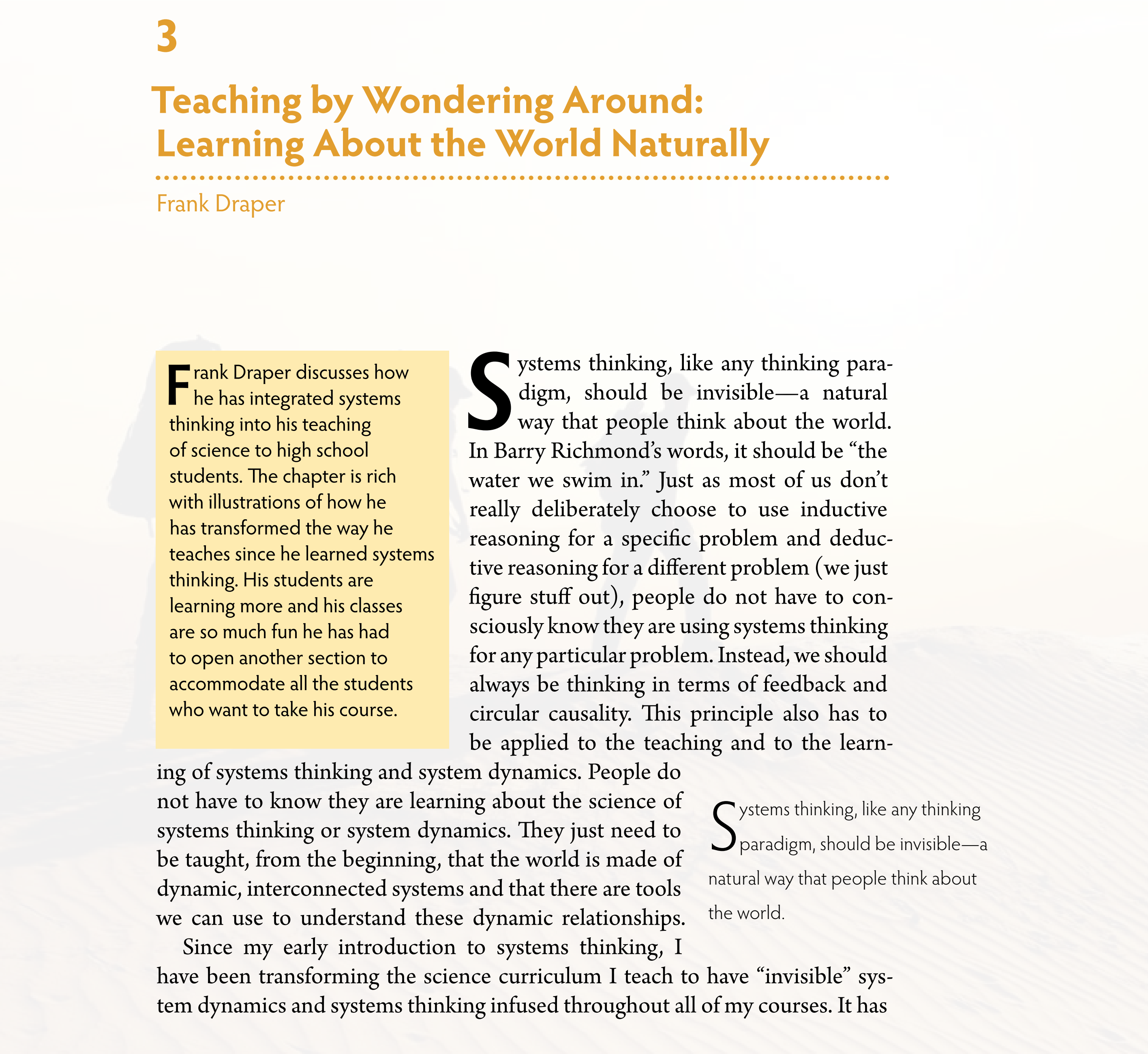

3

Teaching by Wondering Around: Learning About the World Naturally

Frank Draper

Frank Draper discusses how he has integrated systems thinking into his teaching of science to high school students. The chapter is rich with illustrations of how he has transformed the way he teaches since he learned systems thinking. His students are learning more and his classes are so much fun he has had to open another section to accommodate all the students who want to take his course.

Systems thinking, like any thinking paradigm, should be invisible—a natural way that people think about the world. In Barry Richmond's words, it should be "the water we swim in." Just as most of us don't really deliberately choose to use inductive reasoning for a specific problem and deductive reasoning for a different problem (we just figure stuff out), people do not have to consciously know they are using systems thinking for any particular problem. Instead, we should always be thinking in terms of feedback and circular causality. This principle also has to be applied to the teaching and to the learning of systems thinking and system dynamics. People do not have to know they are learning about the science of systems thinking or system dynamics. They just need to be taught, from the beginning, that the world is made of dynamic, interconnected systems and that there are tools we can use to understand these dynamic relationships.

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Since my early introduction to systems thinking, I have been transforming the science curriculum I teach to have "invisible" system dynamics and systems thinking infused throughout all of my courses. It has

Frank Draper grew up in southern California and received a B.A. in biological sciences from California State University, Fullerton. After working as an industrial chemist, a newspaper columnist, and a park ranger, he earned a B.S. in biological sciences and a teaching certificate from St. Cloud State University in Minnesota. He began teaching middle and high school in Minnesota in 1979. After moving to Arizona in 1986, he earned a M.Ed. in secondary education and a Ph.D. in teaching and teacher education from the University of Arizona. He has been teaching in Catalina Foothills school district since 1986 and teaching the field courses since 1994.

been a lengthy but rewarding task. Science, as it is generally taught in our country, is mostly a series of facts unrelated to each other in terms of dynamic relationships. Most states, these days, have a set of curriculum standards with lists of factual pieces of science content that need to be covered, but rarely are any of these connected in any meaningful, real-world system of nature. If relationships are taught, they are usually either through correlations or through the "laundry list of facts." Barry talked about this in his article, "Systems thinking: Critical thinking skills for the 1990s and beyond," as well as in his *Introduction to Systems Thinking Guide*, which form the basis for the introductory chapter of this book.

However, I have been able to cover the state-required benchmarks while embedding them in an integrated, systems-based course. I teach the field courses at Catalina Foothills High School in Tucson, Arizona. The standard field sciences course is open to juniors and seniors, and it fulfills the graduation requirement of a third-year laboratory-based course. The honors, advanced field science course is for seniors who have demonstrated high achievement in the standard field science course and wish to delve deeper into the variety of sciences that involve outdoor research.

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These courses integrate many sciences, combining anatomy, physiology, evolution, biogeography, ecology, geology, hydrology, chemistry, physics, meteorology, anthropology, and astronomy as well as natural resource management into a unified understanding of how nature works. As an example, whenever my students learn one aspect of the natural world, such as the physics of thermodynamics, they also learn how that component affects many parts of the world they live in: plate tectonics, cumulonimbus storm build-up, and the anatomical and physiological adaptations of animals for controlling heat gain and loss.

tracing connections

I met Barry in 1988, when I was teaching eighth-grade science at Orange Grove Middle School in Tucson, Arizona. Gordon Brown, the retired Dean of Engineering from MIT, lived in our school district, and this was my connection. Gordon had a long history with system dynamics from its beginnings at MIT, and he devoted his retirement to getting it established in public schools. Gordon met me in my classroom one spring afternoon, described system dynamics to me, and asked if I would be interested in pursuing it as a way of teaching the interconnections in the world. I was hooked.

That summer Gordon facilitated getting me, along with other Tucson teachers, invited to a two-week system dynamics training course at Stanford University. It was an incredible opportunity. Besides Barry, my teachers included several other contributors to this book: Steve Peterson, Khalid Saeed, and Ali Mashayekhi. During that initial training, I was finally able to put a name, a science, and a set of tools to the indefinable spark I just knew was lacking from my teaching.

After that course, Barry and I met numerous times. As I gained experience teaching system dynamics and systems thinking to both students and teachers, Barry and I had many conversations about learning, especially about learning systems thinking and system dynamics. We would talk, mostly agree and sometimes, rarely, disagree about how people learn systems thinking and how to best teach it. I think we were trying to figure out what it was we wanted to accomplish by teaching people to be systems thinkers.

Systems Thinking Embedded in Physics

My students learn about the physics of thermodynamics by learning about specific dynamic systems in which the laws of thermodynamics play an important role. For example, Figure 3-1 shows a behavior-over-time graph of animal temperature. A model of animal temperature is shown in Figure 3-2. This model was actually modified from a cooling-coffee-cup STELLA model (such as the one on the Creative Learning Exchange website, http://clexchange.org).

By completing multiple runs of the model as shown in Figure 3-3, comparing the size of animals, their insulation, the ambient air temperature, and whether they are warm- or cold-blooded, my students are able to come up with a general statement not only about thermodynamics (the role of ambient temperature and mass in determining heat loss rates), but also general statements about animal adaptations (what problems small animals face compared to large animals in hot

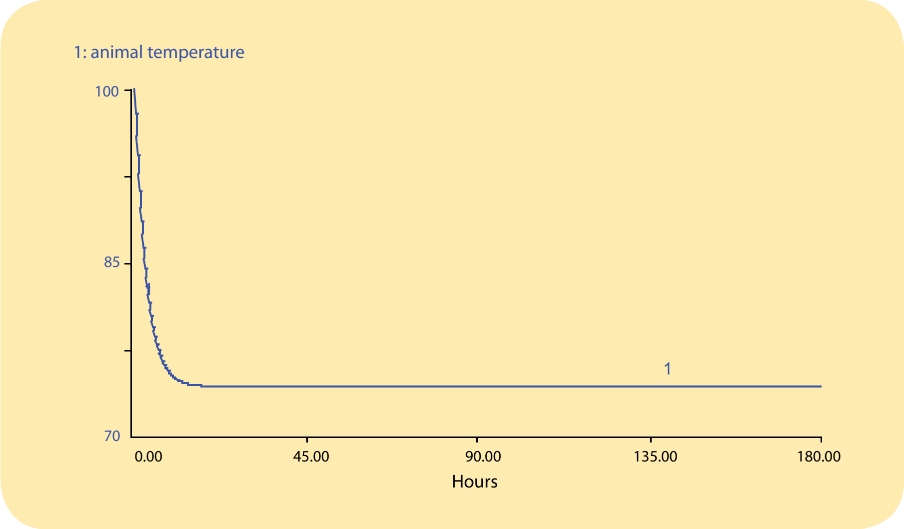


Figure 3-1. Animal temperature over time

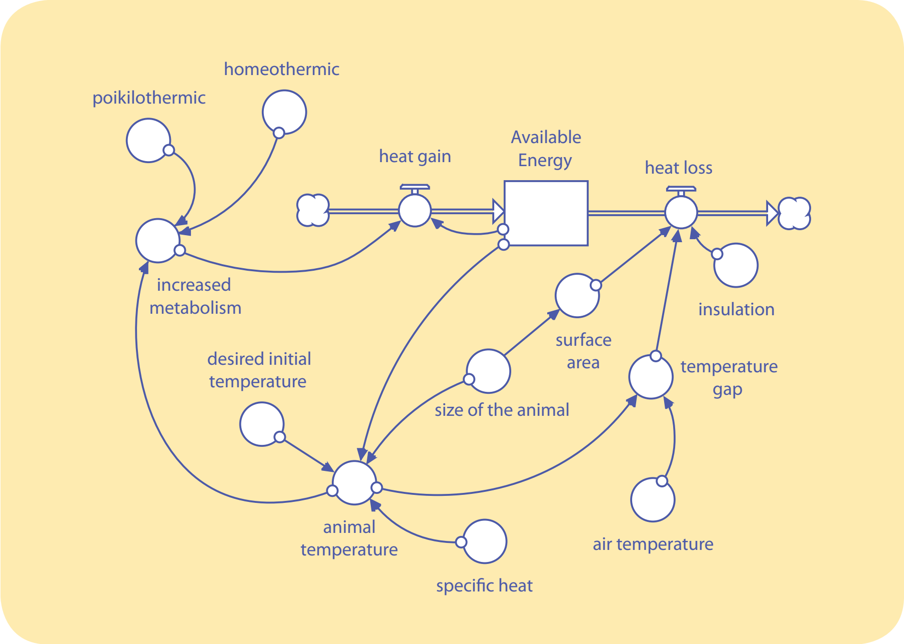
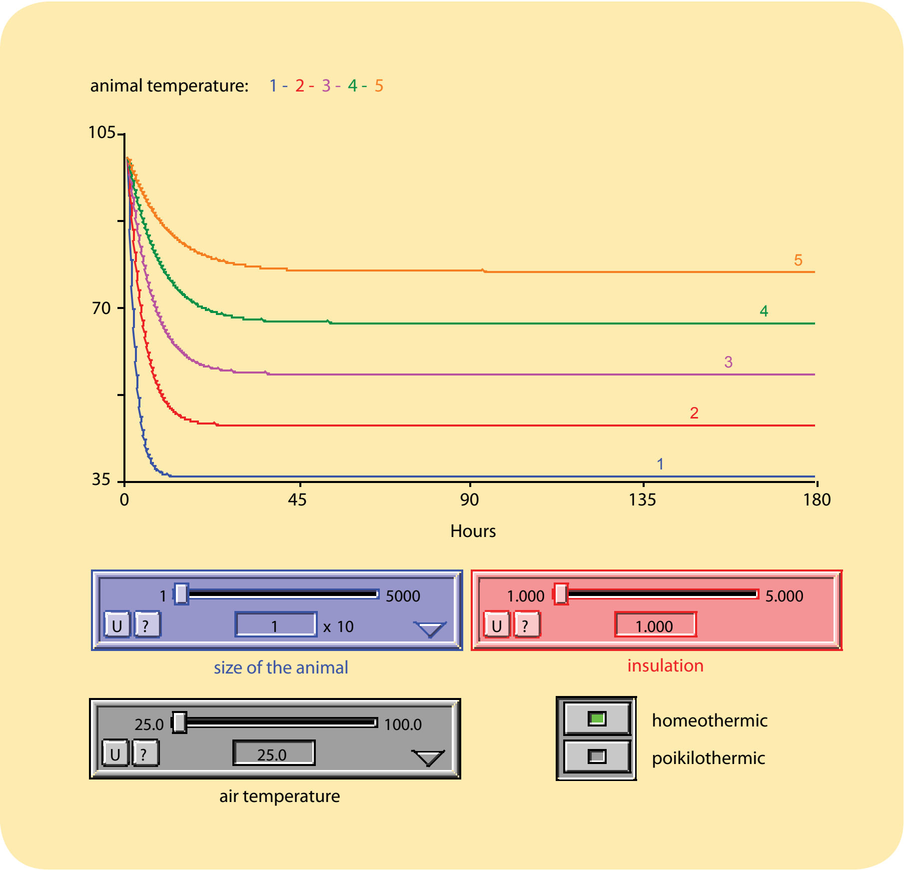


Figure 3-2. Model of animal temperature

and cold environments; what problems cold-blooded animals face compared to warm-blooded animals; what it is that insulation really does for animals).

This is the first STELLA model my students use in my class. I do not discuss STELLA, systems models, systems thinking, or system dynamics. I merely show them how to use the software and off they go exploring the system.

The next day, they explore a U.S. Geological Survey (USGS) website about plate tectonics, thermodynamics, and the rock cycle (http://pubs.usgs.gov/publications/text/dynamic.html). Although not a system dynamics website, the information emphasizes the dynamic nature of plate tectonics and how internal Earth forces interact in complex ways to create the various rock types and geologic features we find in the world.



size of the animal: 1

insulation: 1.000

air temperature: 25.0

☑ homeothermic

☐ poikilothermic

Figure 3-3. Exploring the system with multiple runs

Scientific and Dynamic Thinking

After the initial thermodynamics lesson, the students learn about cumulonimbus cloud build up (towering thunderstorms build up over campus every afternoon at the end of our Tucson summer monsoon season). The feedback relationships between rising warm air, ambient cooler air, vapor-to-liquid phase changes, latent heat release, and the continuing rising of air are presented as a causal loop, without naming the tool itself. My students just automatically draw the loops in their notes and ask questions about the feedback relationships, without ever knowing that this is a basic tool or knowing the name of the tool. Figure 3-4 shows a quick and dirty causal loop I draw for the students during this lab.

I have my students actually "read" through the causal loop. When a wet air mass in the Tucson summer heats up from the sun, its temperature rises; this lowers the density of the air mass (depicted as a negative link). As a result, the air mass rises in elevation. As it rises, the air mass loses heat to the surrounding air and the water vapor undergoes a phase change into liquid. This water phase change releases latent heat from the water that, in turn, heats the air so it continues to rise (depicted as positive links). As the air mass rises, the water droplets continue to cool and eventually form ice crystals and snow. Gravity causes these droplets and crystals to start to fall, causing a downward movement to compete with the upward lift.

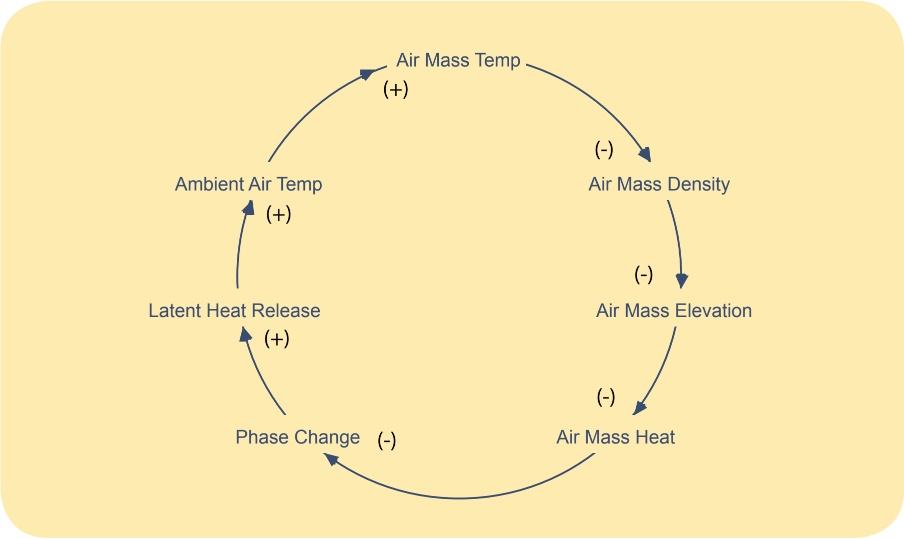


Figure 3-4. Causal loop of temperature

After they show that they understand the circular causality of thunderstorms from this classroom diagram, my students measure the atmospheric pressure, derive the current dew point and use the data in calculations to determine the elevation of condensation or the first phase change in the causal loop. We then go outside and check their math by looking at how high the clouds are building up that day (we can check them against the Santa Catalina Mountains, visible from our school, which rise above 9200 feet). As the towering cumulonimbus clouds quickly build in the afternoon, my students can see the feedback relationship among condensation, cooling, and lift occurring right before their eyes. My students, at this point, are experiencing the results of their own scientific and dynamic thinking.

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Closed-loop Thinking and Generic Thinking

In another laboratory exercise, students look at the behavioral and physiological responses of warm- and cold-blooded animals to various external temperature conditions. In this lab, I have the students "talk through" a causal relationship of cold-blooded animals and heat-regulation behavior with me. I have them complete the following prompts:

- "When a poikilotherm's [cold-blooded animal] body temperature is low, it . . . " (My students should answer "lies in the sun.")
- "When its temperature gets to about 36°C or 100°F, it . . . " (My students should answer "becomes active and eats or goes and lies in the shade to cool down a little.")
- "If that cools it down too much, it . . ." (My students should answer, again, "lies in the sun.")

By now they have figured out the circular thermoregulatory behavior of cold-blooded animals. We follow the same set of prompts, but use the hypothalamus gland's behavior for warm-blooded animals and develop the idea of homeostasis. Although they are not aware of it, my students have just practiced both closed-loop thinking and generic thinking in this simple exercise.

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Operational Thinking

I am not adverse to naming and explaining the tools that I am using. It is just that I have found that if I treat the tools as something special, then my students start to think that systems are special cases of reality, not the way the world works all the time. By the middle of the year, after using STELLA several times, I build, through a classroom discussion, models of population growth, overshoot and collapse, and s-curve limited growth. At this time, I do explicitly discuss the software, the concepts, and the math. By then, my students have a working relationship with STELLA and systems thinking although they don't know it. By the end of the model building exercise, they have had to be explicit in their operational thinking.

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So far I have described both the content and the tools the students are using to learn the content. What I am *doing* during these labs is just as important. I am, in Barry's words, "wondering around." Instead of standing in front of the class and directing exercises for the whole class as a unit, I have all four of these labs going on simultaneously, each involving one quarter of the class. Over the course of four days, my students cycle through all of the labs. During that week, I am wandering between the groups—lecturing here, questioning there, just watching someplace else. My job is sometimes knowledge dispenser, sometimes questioner and tester, but mostly coach and mentor.

By the end of the model building exercise, they have had to be explicit in their **operational thinking**.

One of the most important parts of this process is the creation of the tasks my students do. It is critical that throughout the entire four days, my students are confronting what they already think they know with new information that forces them to reconsider how the world works in a whole new paradigm.

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The Real-World Context

All of the knowledge and skills my students learn, all of the work they do, is ultimately leading to a better understanding of the real world outside the classroom. My real classroom is outdoors. We have about 10 acres of rather wild desert on campus. It is an active Sonoran Desert wash area that flows with flash floods many times during the school year, but is mostly dry. With over thirty species of birds nesting on campus and many more visiting birds, dozens of plant species, a couple dozen reptile species, and several species of mammals, including a resident bobcat we periodically see catching cottontails, it is a resource not to be taken lightly.

My students come to expect me to ask them to apply all of the classroom "stuff" to the real world. Throughout the year, I constantly draw upon previously learned content to provide a richer context for new material, and using this, I have them explain what we see outside in ever increasing complexity.

The excitement for me comes with the unexpected. I truly cannot predict what we might come across when we are outside. Although my learning goals for each outside trek are very clear, I am ready to suspend them when something important happens right in front of us. Those are the opportunities for my students to apply their systems thinking skills in a new context.

One example of this unexpected opportunity to apply systems thinking skills came today. It is March as I am writing this paragraph. This morning, as we were working on measuring different physical aspects of microclimates, a pair of girls came across what they thought was a dead Desert Spiny Lizard lying in the sand. They called me over to look at it. Several students joined us to look at the reptile. As I approached, I saw its head move just slightly.

"I think the judgment of death is a bit premature," I said.

"Really?"

"His head just moved a little."

A boy who had walked with me asked, "Is he just warming up?"

"What do you think?" I asked. "What's the air temperature you've been measuring?"

"About 68°," he answered.

"So . . . " one of the first girls said, "he's trying to get up to about 100° and is just catching the heat."

"I think so," I said. "But what about the zebra tailed lizards? They aren't waiting like this guy."

"They're a little smaller," a couple of them said at the same time. "They don't take as long to warm up. And the baby lizards, the really small ones, are really racing around."

There it was: scientific thinking without ever planning for it. I just needed to be open for the moment to occur. These were my second-year, advanced students who had not worked with the animal cooling model for about 18 months. I am convinced, because I have seen

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it so often, that the systems thinking worldview helps concepts make so much sense that they are retained better.

Such episodes bring up an important point—a point I learned from both Barry and Dana Meadows. Systems thinking and system dynamics, to be truly taught, have to be the way the teacher sees the world and the way he or she lives. Students have to see their teacher personally modeling and using systems thinking to solve problems, to clarify a new phenomenon, and to make sense out of the world. If a teacher does not use systems thinking in his or her own life, then it is merely one more topic or unit that they teach. It becomes school stuff. School stuff is all of that which we "learned" for the test and promptly forgot.

The last conversation I had with Barry, lasting into the early morning hours in Bergen, Norway (and continued on the flight to Oslo the next morning), went deep into a topic I had been working on in my classroom and in the readings. For any deep, lasting learning, teachers and students must enter into a mentor/apprentice relationship in which the teacher is inviting the student into a way of looking at the world and the student is using the thinking tools the teacher is teaching. All of the thinking skills Barry talked about cannot be just "covered" by the teacher, but must be demonstrated through real problem solving by the teacher interacting with the students.

When I do it right, my students see me grappling to understand a complex new phenomenon, either in the field or in the classroom. I look for and encourage those situations when I don't really know what is happening within our world, from something we are observing to some current event in the news. I try to be as transparent in my thinking as I can so that my students observe me spinning my cognitive wheels to put the problem into some kind of context that makes sense.

It is important that they see that I do not have a "right" or "wrong" answer to the problem, but that I have a mental model—a model that only exists in my head—that I can make explicit. And with that mental model, I can come up with an explanation that agrees with the observations and leads me, if the situation warrants, to describe and explain a leverage point that can affect the system in a desired way.

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When my students see that both the content and the thinking skills I teach have meaning in the way I approach my own life, they understand that I mean what I say about the world. When you view the world routinely through a systems thinking lens, it is impossible not to use systems thinking.

A System Dynamics Classroom in a Year-Long Context

My classroom, on any given day, would be recognizable to anyone who has been in school. I have specific daily goals, I am covering state-mandated content, and my students are pretty busy. But the long-term structure would not be so recognizable. I do not teach discrete "units" or unified topics of content for two to three weeks or even for an entire term. I pretty much teach everything all the time. I do this because that is how the world is put together.

What I do is to teach a little bit about a lot of stuff at a time, revisit every concept and thinking skill often during the year, and continue to add complexity and functionality as I go. On any given day, my students might be working on two to four different topics, but continuously putting them together into a unified mental model of how the world is structured.

The human mind is so flexible in its ability to move from one thing to the next that students never seem to have a problem juggling many things at once—and never get a chance to be bored. By the end of the year, I am finally able to put some formal, traditional scientific names to concepts and system structures that my students have been building throughout the nine months of a school year.

The denouement for the year occurs in the last week of school. My students—in pairs—take me for a fifteen-minute walk through the desert. During that time they have a set of prescribed information they have to point out to me, but they also have to be able to answer any question I have about anything we might encounter on the walk. My questions vary depending on the skills of the particular students I am testing at the moment, but most are asked to explain, at least once, an on-going phenomenon of which we are just seeing a snapshot.

By using this process, I am able to see whether the students can put an observation into a continuum of time: what happened before to create what we see and what is likely to come later. By the end of school, they get it. The world, as they explain it to me, is not a series of discrete events but a rich, interconnected structure. They cannot explain the distribution of plants on the walk without including hydrology, physics, soil chemistry, weather, and animal pollination and dispersal relationships.

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My students, in open-ended evaluations at the end of the year, often tell me that they learned more in my course than any other in school, while not having to work as hard. So much of systems thinking *just makes sense.*

Overwhelmingly, students and parents have responded favorably to this kind of teaching and learning. I have room in my courses for 28 students in my one advanced course and 112 in my four first-year courses. I typically get over 40 applying for the advanced course and 225-250 students registering for the first-year course. I have a bit of a soft heart (or head) and have taught an extra section of the first-year course for several years now, teaching 180 students a year about systems thinking by wondering around.

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