In Context

Number 33 Spring 2015

The Newsletter of **The Nature Institute**

#33

Dear Friends,

It was a long, hard, and snowy winter here in upstate New York. No one seems to be able to remember anything quite like the sustained period of extreme cold we have endured, especially throughout the entire month of February, when nighttime low temperatures generally ranged between 0 and –13 degrees Fahrenheit (–18 to –25 degrees Celsius). The snow cover only fully disappeared at the beginning of April. Some who never dreamed of moving south have begun asking themselves uncomfortable questions. Unremitting cold has a way of penetrating all the way through to your bones, so that escape from it can begin to feel imperative.

Perhaps it is not reaching too far to say that a kind of coldness has for a very long while been seeping into much of modern science—most chillingly, into biology. Craig wrote in our last issue about the current push for synthetic biology and the creation of artificial, mechanistic forms of life. Certainly the increasing dominance of an engineering mindset in the science of life—a dominance Craig documented—testifies to a lost feeling for the sentience, inner responsiveness, and "warmth" of living organisms, with their aims, passions, needs, and desires, however consciously or unconsciously expressed.

The same chill has taken thorough hold of contemporary evolutionary studies. A view of inheritance as consisting of the passage of atomistic genes from one generation to the next; the idea that random mutations in those genes are what provide the source material for evolutionary change; the radical ignoring of the living creature as a center of intention and activity in its own right; the reduction of the very idea of evolution to a kind of logical algorithm that tells us in advance how evolution works, without regard for observation of actual organisms—none of this would be possible if biological thought were animated more deeply by a passionate, humane, objectively attentive, and warm-hearted interest in organisms themselves.

In this issue Craig turns to one type of organism—the frog—and asks how much we really know about how it arises from the fertilized egg and tadpole. It is the creative and never fully predictable activity of the organism to which he draws our attention. He makes of it a meditation that cannot help but have implications for our study of evolution.

Steve, having been invited to participate in an important new online resource called "The Third Way of Evolution," tells you a little bit about what motivated the founders of this new website, and shares with you the remarks he was asked to submit for publication on the site.

Bruno discusses his experience working with two California vineyards to help refine their composting processes. Compost—now there's an approach to biological warmth we didn't necessarily anticipate in beginning this letter! But Bruno nicely heats up the topic through his call to make compost an essential and vital part of the life of the farm.

Finally, it's hard to think of anything that releases more soul-warmth into the world than a beautiful flower. Reinout Amons, a Dutch biochemist, friend of The Nature Institute, and participant in one of our Goethean science courses, treats us to an observational discovery he made about the morning glories in his garden.

May you find a warming sustenance of your own in this Spring issue of *In Context*!

Craig Holdrege — Steve Talbott

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The Nature Institute

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Copies of *In Context* are free while the supply lasts. Past issues are posted on the Institute website. Our *NetFuture* newsletter is available at: http://netfuture.org.

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An Open Secret — The Calyx of *Ipomoea purpurea*

Reinout Amons

Five are brethren
Two are bearded
Two are born without beard
One of the five
Is not bearded on both sides.

Quinque sunt fratres
Duo sunt barbati
Duo sine barba nati
Unus e quinque
Non habet barbam utrimque.

Attributed to Albertus Magnus

Figure 1. Left: Rose flower bud showing three of the five sepals. Right: A different rose flower opening with sepals folding back.

Some readers of *In Context* may know a special feature of most roses (especially those related to the dog rose, *Rosa canina*) with respect to their calyx leaves. The calyx consists of five green sepals, which are the leaves that encase the flower before it opens and then fold back as the bud opens (see Figure 1). Figure 2A shows a sketch of the differently shaped sepals. The shape difference is due to little leaf-like extensions (which I will call "fringes") that grow out of the sides of some of the sepals. In the above verse, the medieval scholar Albertus Magnus (1193-1280) calls the sepals five "brethren" and the fringes their "beards." What's interesting is that the sepals do not all have fringes and those that do are fringed differently: Two of them have fringes on both margins ("are bearded"); two have no beard whatsoever; and one sepal has a beard at only one side.

What may appear to be a random arrangement regarding the fringes reveals by closer inspection a pattern: going from one calyx leaf to an adjacent one, a fringed edge always alternates with a smooth edge and vice versa. In this way the space between any two sepals always has one fringed and one smooth side. Due to the way the sepals are spatially arranged (Figure 2B), when the calyx is still closed, a smooth margin is always overlapped by the fringed margin of its neighbor. This can also be seen in the closed bud in Figure 1.

Until recently I thought that this surprising pattern was unique to roses, since typically the sepals in the calyx of a flower have similar forms.

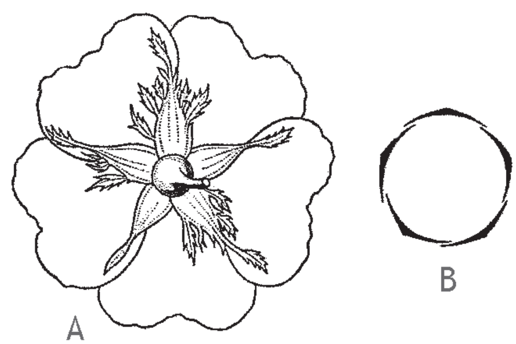


Figure 2. A: Sketch of the rose calyx with its five sepals, seen from below. B: Diagram of the spatial configuration of the sepals when the bud is partially closed. (From Troll 1959, p. 62.)

Last fall, we enjoyed in our garden in The Netherlands the flowering of a tropical morning glory (*Ipomoea purpurea*). The species originates from Central America, but now is widespread throughout the United States and Southern Canada. This climber also blooms most beautifully in Dutch gardens in late summer, with funnel-like purple flowers. Each flower consists of five fused petals called a corolla and has a diameter of about four to five centimeters . Before the corolla opens you can see the green

Figure 3. Left photo: *Ipomoea purpurea* flower in unopened bud stage and, next to it, a flower that is beginning to wilt. Right photo: *Ipomoea* with fully open flower.

bud with its spiraling, furled tip (Figure 3). It starts to open very early in the morning, long before sunrise. The corolla is open during the morning and already, a couple of hours after noon of the same day, it starts to wilt and soon falls off. In contrast to the very short-lived corolla, the sepals remain attached to the stem. The fruit swells and matures in their midst.

I noticed that the sepals are unequally formed, and suddenly it became clear to me that the sepals of *Ipomoea purpurea* do what Albertus Magnus described for the rose calyx—but a bit differently! *Ipomoea* also has two different types of sepal margins that alternate. But instead of conspicuous leaf-like fringes, it has more inconspicuous hairy, rough sepal margins, and the smooth margins are paper-thin and pale in color. Figure 4 shows five views of the same calyx surrounding the maturing fruit, with a different sepal at the front in each view. This order of the sepals, seen from below, is shown in Figure 5. What becomes clear is that the five sepals are ordered as in the rose! A smooth margin in one sepal is opposite a hairy margin in its neighbor. And, as in the rose, the smooth margins are partially overlapped by their hairy-margined neighbor.

It is fascinating how such a pattern repeats itself in these two very different plants. But you have to look closely to see this "open secret." Little wonders in a Dutch garden!

Reinout Amons, a friend of The Nature Institute, participated in our 2006 eleven-week course on Goethean science. An avid observer of plants, he is a retired associate professor of biochemistry.

Reference

Troll, W. (1959). *Allgemeine Botanik*. Stuttgart: Ferdinand Enke Verlag.

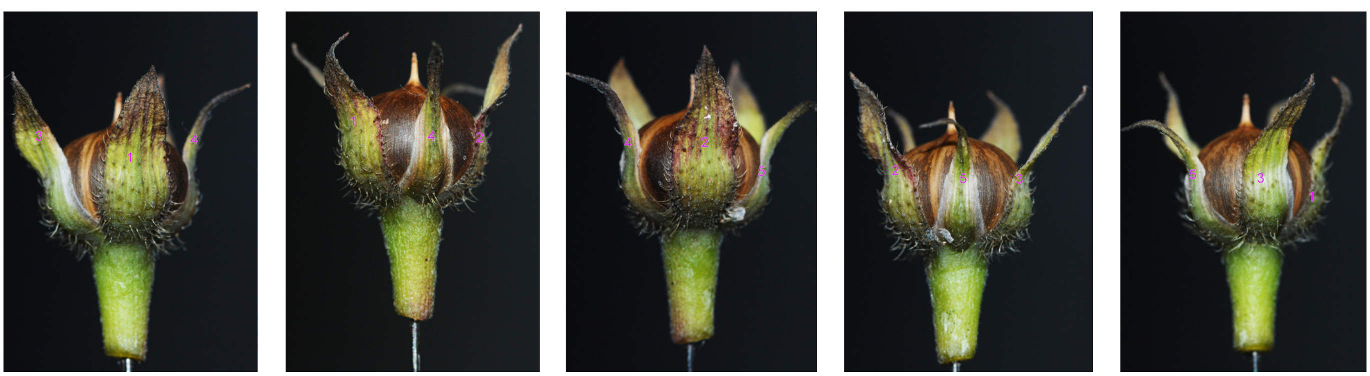


Figure 4. *Ipomoea* sepals enclosing a ripe ovary. Each panel shows a different sepal in front.

Figure 5. *Ipomoea* calyx seen from below, from two slightly different points of view. Note how the pale smooth margins are overlapped at their base by the rough margins of their neighboring sepals.

Evolution: A Third Way?

Stephen L. Talbott

In recent years we've seen increasing numbers of biologists who are dissatisfied with conventional ("Neo-Darwinian") evolutionary theory — biologists who, it would appear, are also unhappy with the resistance of an entrenched scientific establishment to the consideration of new ideas. Part of this resistance, I think it is safe to say, is owing to the fact that the establishment has taken on a kind of siege mentality owing to assaults from the intelligent design community. Unfortunately, when scientists and scholars retreat into an us-versus-them mindset, many important distinctions and possibilities of thought tend to be lost, sacrificed to the tactical exigencies of the conflict.

So it was that, during this past year, a group of biologists inaugurated a website called "The Third Way of Evolution" (http://thethirdwayofevolution.com). Led by figures such as James Shapiro, a University of Chicago microbiologist and author of *Evolution: A View from the 21st Century,* and Denis Noble, an Oxford physiologist who is president of the International Union of Physiological Sciences and author of *The Music of Life,* the group describes its purpose this way:

> The vast majority of people believe that there are only two alternative ways to explain the origins of biological diversity. One way is Creationism that depends upon intervention by a divine Creator. That is clearly unscientific because it brings an arbitrary supernatural force into the evolution process. The commonly accepted alternative is Neo-Darwinism, which is clearly naturalistic science but ignores much contemporary molecular evidence and invokes a set of unsupported assumptions about the accidental nature of hereditary variation. Neo-Darwinism ignores important rapid evolutionary processes such as symbiogenesis, horizontal DNA transfer, action of mobile DNA and epigenetic modifications. Moreover, some Neo-Darwinists have elevated Natural Selection into a unique creative force that solves all the difficult evolutionary problems without a real empirical basis. Many scientists today see the need for a deeper and more complete exploration of all aspects of the evolutionary process.

The website has now achieved considerable weight, revealing a remarkable diversity of viewpoints among the scientists, philosophers, historians, and other scholars concerned with evolution. And this is perhaps the site's primary value. It succinctly presents viewers with a rich variety of resources to pursue, depending on their interests. None of the viewpoints expressed there is endorsed, and none of them is necessarily consistent with any of the other viewpoints presented on the website. "Our goal is simply to make new thinking about evolution available in one place on the web." The website is a healthy — and, in the current intellectual environment, a rather unexpected — reminder of how downright *natural* it is in any living, vital field of science to see creative thinking going on in many different directions.

One more or less common element uniting all those scientists and scholars appearing on the website is a rejection of the idea that "small random mutations are the main source of new and useful variations." After all, as the home page puts it,

> We now know that the many different processes of variation involve well regulated cell action on DNA molecules. Genomes merge, shrink and grow, acquire new DNA components, and modify their structures by well-documented cellular and biochemical processes.

To turn away from a preoccupation with random mutations and the "mechanism" of natural selection, focusing instead on the life of the organism, is to invite a consideration of the organism as an active agent in the evolutionary process. Perhaps even now not many are quite ready to embrace fully what this could mean, but we can look forward to some interesting developments.

As it happens, I was quite unexpectedly invited to join the group this past January. Participants are asked to submit (for the website) a statement about the nature of their own work, together with comments regarding their approach toward an understanding of evolution. For my remarks, which are necessarily rather dense, see the next page.

Whole Organisms Evolve, Not Just Their DNA

Following are the remarks Steve submitted for inclusion in "The Third Way of Evolution" website (http://thethirdwayofevolution.com).

Personal Profile. After many years working in the engineering organizations of computer manufacturers, Talbott joined The Nature Institute as Senior Researcher in 1998. He has long been concerned about distortions introduced in biology by technological thinking. He attempts to show how our understanding of the organism and its evolution is transformed once we recognize and take seriously the organism as an intelligent agent meaningfully (though not necessarily consciously) pursuing its own way of life.

When molecular biologists formulate their fundamental questions (how are DNA breaks repaired? how does the cell divide? how are RNAs localized in the cell? how are protein amounts regulated?) they seem to believe that the organism is actually capable of solving such problems. That is, they believe it engages in the pursuit of ends, organizing its activity according to the idea or logic of the tasks at hand. But they commonly try to answer these questions merely by tracing and adding together local causes — showing how one thing controls another, how this makes that happen. Such making, however, never reaches to the biologically and contextually expressed intentional activity that informed the original questions. Causes by themselves do not pursue tasks. The always lawful molecular proceedings in the organism are vital to analyze, but to offer these proceedings as explanations of a living performance is misguided. If the organism is able to coordinate physical causes for the satisfaction of its own needs and aims, then it governs those causes at least as much as it is governed by them.

How should we understand this governing? We need a reconciliation of the causal and intentional ways of thinking — a reconciliation that does justice to them both without a dualistic cleaving of the world.

Statement on Evolution. We cannot understand evolution without understanding the life of the organism. This life is expressed in well-coordinated processes; organisms are not mere collections of molecules, "informational" or otherwise. What is inherited, then, are ways of doing things with the available resources. If an organism can differentiate and organize its tissues to form liver and skin, retina and endothelium, brain and heart — and if it does this adaptively and improvisationally amid the not always predictable conditions in which it finds itself — then why not assume that these same well-directed powers of adaptation and improvisation are brought to bear also upon the formation of its gonads and germ cells? The validity of this assumption is rapidly being confirmed today.

It may be argued that organismal performances (ways of doing things) cannot figure in evolution because they do not offer a sufficiently stable content for natural selection to work on. But this is, first, to accept the incoherent notion that the environment, as the "grim reaper" of natural selection, is the creative agent in evolution, and, second, to overlook that organisms, in responding to this environment, are the capable agents we observe them to be in all aspects of their own development. But if organisms *are* capable agents — agents harmoniously demonstrating their intention to live a life of a certain character even when this requires overcoming aspects of their environment — we should ask, not only how they may accidentally contribute to the fitness and survival of future generations, but also how they may creatively contribute to the evolving character of those future generations.

DNA sequences are appealing as the sole or primary materials of inheritance because they give us conveniently and quantitatively trackable things. But stable things and our own mathematical convenience are not necessarily the best guides for understanding life and change. What if the more pressing need is to learn to track a qualitative and coherent organizing reality we have hardly yet begun to recognize because we haven't yet even thought to look for it?

Developing a Qualitative Understanding of Nature: Animals, Humanity, and Evolution

This year's week-long winter course in February was attended primarily by young farmers and apprentices. They brought a quiet interest and an openness to engage in the different activities. Our courses sometimes surprise participants since it is not at all clear at first why, for example, a course related to agriculture should have one session each day that involves doing projective geometry. And so it was this year, but by the end of the week a number of participants wrote that this was their favorite part of the course! Why? Because, I think, it was new and unusual, it involved individuals in the activity of drawing, it challenged thinking in unexpected ways, and then, at the very end, it forged some mind-stretching connections to the work in other sessions.

When we plan such a course, Henrike and I do not necessarily know what kind of connections between the work in geometry and the work in biology will appear. The idea is to explore deeply in two directions and then see what reveals itself. The revelations and insights come only out of the process and they are often surprising to us as well.

One important idea that developed in the geometry this year was that every finite form is related to a particular structuring of the whole of space. Nothing is truly separate. Every form is always, through and through, related to a larger whole. This idea grew in potency as we considered animal forms and the relation of animals to the human being in evolution. We could truly begin to sense not only the uniqueness of cow, pig, and horse, but also the interconnectedness of life forms in a deep and expansive way. We saw that, as human beings, we have the ability to let every other being come to expression in us. We are connected with the whole of life. How seriously do we take this fact? What can we do to bring our own intentions into a healthier relation to the beings with which we are connected? CH

In their written evaluations of the course, two farm apprentices explained how the different activities "held together" for them:

"I can tell this course was planned out very thoughtfully and intentionally. Unlike my educational experience growing up, I was able to connect the different activities and lectures, and that helped my understanding. My intellect and spirit have both been stimulated, refreshed, and challenged."

"This week has been a breath of fresh air, a nuanced and sensible building-up of a cohesive and sensitive worldview from which anyone could benefit, regardless of their inclination toward the particularities of faith and philosophy that led to it. Overall, a nice balance of instruction and interaction, observation and creativity, tangible and abstract, although I would not object to more time spent on animals (either in general or particular). Discussion of domesticity especially interesting and informative."

Of Wines and Compost

I have never had a farmer or gardener approach me with a more vehement desire to produce high quality compost than was shown last March by two biodynamic winegrowers from California. I believe their enthusiasm and commitment toward improving their composting practices have something to do with the highly refined science and art of making wine itself.

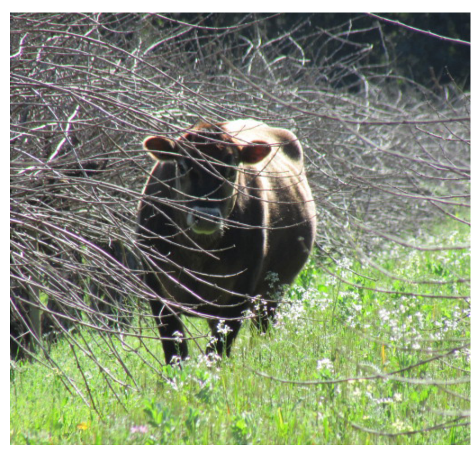
My journey began in Sonoma County at the biodynamic Benziger Family Winery. Located in the Sonoma Mountain wine-growing region, the Benziger ranch is tucked into a bowl-shaped valley eight hundred feet above sea level. The area has a unique and impressive geography. What struck me most, however, was the rich biodiversity and appealing aesthetics of the vineyard, together with the owners' commitment to the health, not only of their vines, but also of their entire farm. For example, they created a special "insect garden." With its diverse plant life, the insectary hums with life as it attracts butterflies, humming birds, and numerous beneficial insects. There is also a lovely sheep flock that grazes among the vines along with Scottish Highlander cattle. The quality of the Benziger wine reflects the context and wholeness of the farm landscape.

After three days at Sonoma Mountain, I headed north to Mendocino County, home of the first organic and biodynamic certified vineyard in the country. Frey Vineyards is located on the beautiful slopes of Redwood Valley. The familiar palm trees, so present at the beginning of my trip, were now replaced by a landscape where towering redwoods grow. Warmly welcomed by Luke Frey and his family, I was engaged in conversations and practical activities regarding the improvement of their composting practices. Luke also organized a public workshop where I spoke about the "The Art and Science of Composting and Its Inner and Outer Gesture."

The Lesser Cousin of Wine

An intrinsic part of any vineyard and winemaking process is the grape pomace. After the grapes are crushed so their sweet and precious juice can be further transformed into wine, a much less romantic substance is left as a byproduct—the pomace. Hundreds of thousands of tons of skins, stems, and seeds are produced each year. For most wine growers, this is a noxious and troublesome material. Left alone the pomace can quickly emit intense foul odors. It has a very low pH, and if it is carelessly stockpiled in wet conditions it can begin to produce acetic acid. Although its carbon/nitrogen ratio seems at first ideal for composting, it behaves as a carbonaceous material because of the high lignin content of all its stems. As a whole it is relatively rich in nitrogen, potassium, and calcium. These and other characteristics make pomace a peculiar and unusual material that is very challenging to work with.

Pomace is often approached as a burdensome waste. "Externalizing" it—transferring the burden of it to the environment—often seems the best and easiest solution. In many places, after the grapes are crushed, the pomace is hauled out of the vineyard and dumped elsewhere. Yet, just as cow manure is an extension of the dairy herd and belongs to the reality of the farm, so, too, pomace belongs to the vineyard and needs to find a worthwhile place as part of the winemaking process.



Redeeming the Pomace

Mike Benziger, founder of the Benziger Family Winery, has a very different perception of pomace. Always striving to foster the health of his farm as a whole, he clearly sees the pomace as an important and integral part of the nutrient cycle of the ranch. At the suggestion of Matias Baker, the farm's biodynamic consultant, he had invited me to help them improve the quality of their compost and their composting process.

Over three days we had numerous conversations envisioning the compost as an integral part of the vineyard, where one is *continuously engaged* with the compost process. We also actively worked to improve some of the current practices, and reviewed the general principles for mixing fresh material and building a new compost pile.

What resonated throughout that whole week—at both farms—was the realization and confirmation that the composting of the pomace is an integral part of any vineyard. Compost needs to be cared for throughout the whole growing season; it cannot be something that is attended to only when there is time. The farm community needs to develop a conscious and fully engaged sense of responsibility for all aspects of composting.

The art of mixing fresh decaying organic matter and guiding this living process through a de-composition and re-composition to a final composition is as much an art as the creation of wine. For folks so dedicated and committed to the quality and art of wine fermentation, the idea of giving the same care and attention to the life of the pile and its contribution to the soil does not seem foreign.
Compost can contribute to the "terroir" of a wine. (The word refers to the qualities of earth, air, water, and light—all the environmental qualities—through which a wine gains its distinctive appeal.) Pomace, instead of being a burdensome waste, can be transformed into humus—a life giving substance. Ultimately, composting should not be seen only as a way of improving the quality of the wine, but it should be seen as a free offering, given out of love for the Earth and Humanity.

Bruno Follador

Out and About

• **Techno Utopia Teach-In.** (Audio available; see below.) In October, 2014, Craig gave a presentation at this teach-in sponsored by the International Forum on Globalization in New York City. There were 58 different presentations over two full days—each presenter was given 20 minutes—and the presentations were grouped according to different overriding topics (see http://ifg.org/techno-utopia/). Speakers included Bill McKibben, Vandana Shiva, and Nature Institute advisory board members Langdon Winner, Wes Jackson, and Andrew Kimbrell, among many others.

Craig's talk was called "The Hyper-real and the Real: Humans in the CyberWorld." He began his talk by showing a beautiful short video of a fox. You can view it at: https://www.youtube.com/watch?v=D2SoGHFM18I. We recommend that you view it first without sound (which is how Craig showed the video) and then listen to his talk, which can be heard at: http://ifg.org/techno-utopia/full-audio-of-teach-in/#mep_34.

• **What is Phenomenology?** In February Craig contributed to a four-day conference for high school science teachers at the Summerfield Waldorf School in Santa Rosa, California. He led a session each morning for all participants on "The Experiential Foundations of Phenomenology." Each afternoon he worked with a smaller group, mainly biology teachers, to explore some key issues in evolution.

• **Developing Living Thinking: Geometry and Plant Study.** At the end of February Henrike and Craig gave a public weekend workshop on this topic. The event took place in Pasadena, California and was hosted by the Los Angeles branch of the Anthroposophical Society.

• **Projective Geometry in a Social Therapy Setting.** In March and April Henrike taught a five-session course in Projective Geometry for students attending a Social Therapy Program at the Camphill community in Copake, New York.

• **Characterizing Plants and Animals.** In March Craig gave a half-day workshop at the Pfeiffer Center in Spring Valley, New York, on the different way-of-being of plants and animals.

• **Biology Teachers, Evolution, and the Giraffe's Neck.** At the end of March Craig gave a weeklong seminar on evolution for high school biology teachers at the annual International Refresher Week for high school teachers in Kassel, Germany. This week offers courses in both English and German, and is attended by around 200 teachers from many different countries. Craig also gave a talk to all participants on "Does the Giraffe Have a Long Neck? The Challenges of Holistic Biology."

• **In the California vineyards.** In March Bruno spent a week consulting with the Benziger Family Winery in Sonoma County and the Frey Vineyards in Mendocino County. See our story on page 8.

• **Waldorf Educational Research.** In April, Henrike and Craig participated in a weekend gathering in Amherst, Massachusetts, organized by the Research Institute for Waldorf Education. The topic of the gathering was "context in education." Craig and Henrike gave a presentation.

• **Composting in Ontario and Virginia.** Bruno has been invited to give an early May workshop at the Thyme Again Garden organic farm in Carrying Place, Ontario, a rural community just north of Toronto. The workshop title is "The Art and Science of Composting and the Qualitative Language of Ehrenfried Pfeiffer's Chromatography." In May he will also conduct workshops on the same topic at The Nature Institute and the Josephine Porter Institute for Applied Bio-Dynamics, an agricultural research and educational institute in Woolwine, Virginia.

• **Amazon River Adventure.** By February, our upcoming trip was fully booked. Sixteen participants, from Brazil and the U.S., will join Mark Riegner and Craig Holdrege from May 31 to June 12. We will be exploring the plants, animals, and ecology of the Amazon and working to illuminate our experiences through reflections upon Goethean phenomenology.

• **At Schumacher College.** In September, Craig will again teach for a week in the Holistic Science masters degree program at Schumacher College in the United Kingdom. His topic this year is "Goethe's Way of Science."

• **Does Science Evolve?** At the end of September Henrike and Craig will participate in a conference on "Evolving Science" organized by the Science Research Lab at the Goetheanum in Dornach, Switzerland. The aim of the conference is to bring people together from around the world whose work is inspired by the Goethean approach to science and its extension through Rudolf Steiner's work.

• **Goethe in Texas.** Craig has been invited to give two talks in October at Texas State University on Goethe's approach to science. He will speak to faculty and students.

Spring and Summer Events at the Institute

An Introduction to Projective Geometry
A workshop in eight sessions with Henrike Holdrege
Mondays, 9:00 am to 10:30 am: March 16, 23, 30; April 6, 13; May 4, 11, 18
This work will continue in the fall.

Monday Nights with the Stars
A course in four sessions with Henrike Holdrege
Mondays, 8:00 pm: March 23, 30; April 20, 27

Mathematics Alive! - The Geometry of the Platonic Solids
A weekend workshop for middle school teachers with Henrike Holdrege and Marisha Plotnik
April 10-12.

The Art and Science of Composting and Ehrenfried Pfeiffer's Chromatography
A weekend workshop with Bruno Follador
May 1-3

Awakening to Nature's Open Secrets: Pathways in Science and Art
A five-day course with Craig Holdrege, Henrike Holdrege, and faculty of the Hawthorne Valley Alkion Center, a neighboring adult education organization
June 21-26

Miracles of Light and Color
A five-day course with Henrike Holdrege and Jennifer Thomson
An immersion in Goethean science and water color painting
July 9-14

It's About Color
A talk and slide show by Jennifer Thomson
Jennifer will discuss her paintings of the last seven years.
Sunday, July 12, 7:30 pm

For more information about these events, please visit the calendar on our website: http://natureinstitute.org/calendar.

Thank You!

To all those generous and supportive friends who have contributed money, services, or goods to The Nature Institute between October 1, 2014, and March 31, 2015: you have our heartfelt thanks! We'd like to give our special thanks to the Edwards Mother Earth Foundation for its challenge grant for the Living Soils initiative, and to all of you who helped us meet and even surpass the funding goal.

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Do Frogs Come from Tadpoles?

Understanding Development as Creative Activity

Craig Holdrege

Where does a frog come from? The answer seems obvious. It comes from a tadpole. But does it?

Surely, without the tadpole the frog does not develop. But just as surely, nowhere do we find the frog in the tadpole. The frog comes into existence as the tadpole disappears out of existence. We need to be keenly aware of what we mean, and what we don't mean, when we say, "A frog develops out of a tadpole"—or a tadpole out of an embryo, or an embryo out of a fertilized egg, or an adult human being out of a child.

As we will see, when we give careful attention to what is actually happening when a new phase of life develops out of a previous stage, there are large implications for our overall understanding of developmental processes. New and exciting questions arise about how we conceive of development—including that trans-species developmental process we call evolution.

One caveat: I will be limiting my descriptions to those tadpoles that develop into frogs (not the tadpoles that develop into salamanders). I will focus on pond-dwelling tadpoles and their metamorphosis into land-dwelling frogs, as exemplified by many species that live in temperate climates. There is an astounding variety of ways in which different species of frogs develop—some have no tadpole phase, some have tadpoles that are carnivorous rather than herbivorous, some frogs remain aquatic for their entire life cycle, and so on. Because of this, for probably every characteristic I describe there are exceptions. They are fascinating and warrant consideration when you really want to understand the peculiarities of given species or genera and the variations within the amphibians. But my aim here is to provide a general picture of metamorphosis.

The Life of a Tadpole

Most of you have probably seen tadpoles in ponds and vernal pools. With a thick squat body that abruptly tapers to a long finned tail, a tadpole definitely does not resemble a fish. And yet, tadpoles are fish-like in many of their characteristics. They remain submerged in water and breathe through their skin and gills. They have no limbs, and swim through water via undulating movements of a long boneless tail fin. Like fish, tadpoles have a lateral line organ, which runs along each side of its body and tail, through which they sense movements in water.

Figure 1. Metamorphosis of the European common frog (*Rana temporaria*). Pictured to scale. (Photographs by Tim Hunt, reprinted with permission; http://www.timhuntphotography.co.uk/)

Figure 2. Tadpoles (European common frog; *Rana temporaria*). (Photo by Friedrich Böhringer; wikimedia commons.)

A tadpole typically grazes off of algae that grow on plants, rocks, or at the surface of the water. Tadpoles have a "beak" and rows of denticles in their mouth that function like rasps to scrape off the algae. The denticles do not consist of bone and enamel but of keratin—a protein substance that, for instance, also makes up our fingernails and hair.

The tongue-less tadpole sucks the algae into its throat and the food enters the long intestine where it is digested. There is no stomach. The intestine can be more than ten times longer than the tadpole itself and is its largest internal organ, making up over half of its body mass. Tightly coiled, the intestine takes up about half the space within the tadpole's ovoid-shaped body and is visible through the translucent belly skin.

How long a tadpole lives before it metamorphoses into a frog is dependent on the species and on outer conditions. A wood frog tadpole (*Rana sylvatica*), for example, usually metamorphoses into a froglet within two or three months after hatching in the northeastern United States. The time is shorter when there are higher water temperatures and ample food, and longer when there is colder water and little food. Bullfrog tadpoles (*Rana catesbeina*) grow large—often around four inches (10 cm) long—and, depending on circumstances, can sometimes metamorphose into frogs in

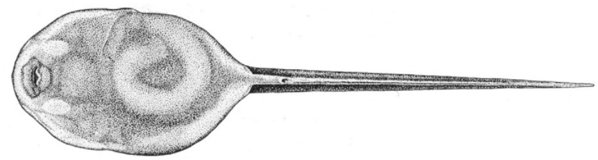

Figure 3. Northern leopard frog tadpole (*Rana pipiens*) viewed from below (ventral; stage 25). Note the coiled intestine visible through the belly skin. (From Witschi 1956, p. 80.)

the fall (four to five months after hatching). But, more typically, they live as tadpoles for two to three seasons before metamorphosing.

Metamorphosis

If you only observed, side-by-side, a tadpole and an adult frog, you would have no idea that the two animals have any connection with each other. The fully aquatic, herbivorous tadpole bears no resemblance to the tailless, four-legged, carnivorous croaking and leaping frog. And yet the two are inextricably connected; the one cannot exist without the other.

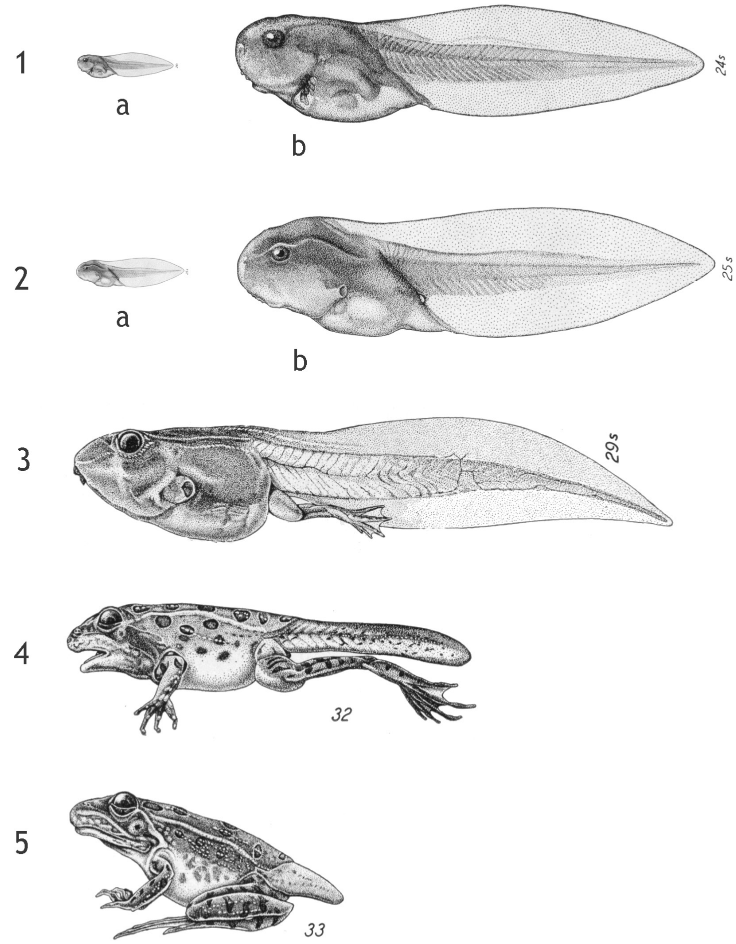

Figure 4. Tadpole metamorphosing into frog (Northern leopard frog; *Rana pipiens*). 1a, 2a, 3, 4 & 5 are drawn to scale, at about 1.2 times natural size. 1b and 2b are enlargements of 1a and 2a respectively. Numbers next to drawings indicate the developmental stages as given by Witschi. (Adapted from Witschi 1959, p. 80-1.)

The first external sign that a tadpole will not always remain a tadpole appears in the gradual development of hind limbs. They originate as little buds from the rear of the torso, grow into paddle-like structures and then elongate into muscular, articulated limbs at the base of the still-existing tail. While the hind limbs grow, the tadpole also grows and the tail remains the primary means of locomotion. The legs come fully into action only after metamorphosis is completed.

While the hind limbs develop over many weeks or even months (this gradual transitional phase is often called "prometamorphosis"), the further transformation of tadpole into frog occurs within a short period of time—often a week. Virtually nothing in the tadpole remains untouched—organs and body parts are wholly broken down and disappear, others are refashioned, and wholly new organs and body parts arise. While it is easy to say "everything changes," we gain a much richer sense of what such a transformation entails when we look at it in more detail. In this case, it is not the devil that is in the details; it is the beauty and awe-inspiring transformative ability of life itself.

Externally, the most marked transformation is the disappearance of the tadpole's tail and the concomitant rapid development of the forelimbs and the growth of the hind limbs. The tail does not fall off. Rather, all its skin, muscle, cartilage, blood vessels, and nerves are internally broken down. The substances arising out of the self-digestion of the tail can be transformed and used to build up new body parts. Being tailless, a young frog is at first considerably smaller than the tadpole was. Depending on the species, it remains small or will grow larger than the tadpole.

A tadpole breathes mainly by taking in oxygen through the thin and highly vascularized skin of its tail. The skin has been compared to fetal skin in mammals. The gills play a lesser role in respiration. Already prior to metamorphosis the tadpole begins to develop lungs and in some species you can see—especially when the water is warm and stagnant—tadpoles swimming to the surface to gulp air into their lungs.

During metamorphosis, while the tail is shrinking in size, the skin of the remaining tadpole thickens. It develops a wholly new pattern of pigmentation and a variety of secretory glands, some of which keep the skin moist once the frog leaves water to live on land. A frog's skin becomes less able to take in oxygen and the lungs develop rapidly into the main organ of respiration while the gills are being broken down. Froglets begin floating near the surface with their nasal openings (nares) just above the water surface to take in air.

The circulatory system is intimately connected with respiration and experiences radical remodeling. All the vessels that serve the tail and gills are reabsorbed and new vessels are formed that connect the lungs to the heart. The blood itself becomes thicker in consistency as more serum proteins are formed. Larval red blood cells—which are formed in the kidneys and liver—die off as the smaller and more numerous adult red blood cells are generated. In frogs most of the blood arises out of stem cells in the bone marrow. Different types of hemoglobin—which bind oxygen in red blood cells—arise and they bind more oxygen than larval hemoglobins.

While tadpoles graze mainly on plant matter, frogs feed on other animals, often insects. This transition means a massive remodeling of its feeding and digestive organs. The tadpole's beak is shed, its denticles are reabsorbed and the mouth as a whole widens. A highly articulated jaw allows the mouth to open wide and in many frogs true teeth form. In the mouth, secretory glands develop as does a tongue, which is muscular and can be quite long. A frog often captures its prey by flipping its tongue out of its mouth, enwrapping the prey with its tongue and then pulling it into its mouth, holding it momentarily with its teeth and then swallowing it whole.

Many herbivores have long intestines in which they digest their food, and this is the case in tadpoles, as mentioned above. During metamorphosis, three-quarters of the intestine degenerates and the inner lining of the remaining intestine thickens, many folds arise in it, and a very large absorptive surface is created. As the intestine shrinks, a true stomach is formed that secretes pepsin, an enzyme that is important for digesting animal food. While the rapid

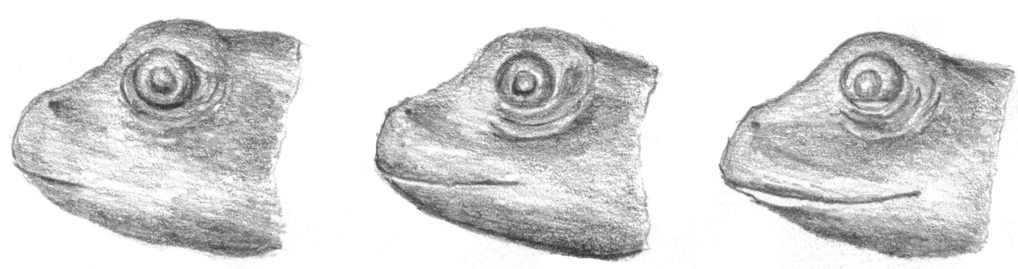

Figure 5. Changes in the shape of the head during metamorphosis (*Bufo valliceps;* Gosner stages 43, 44, & 45). Note the widening mouth. (Redrawn after McDiarmid and Altig 1999, p. 11.)

transformation of the digestive system occurs, the tadpole-becoming-frog hardly feeds.

If you picture a frog leaping—to catch a mosquito that is drifting by or a grasshopper resting on a plant—and you contrast this with the image of a tadpole scraping algae from a submerged stem, you have a sense of two very different ways of being and ways of relating to the surrounding world. This contrasting relation corresponds to a reorganization of the senses and sense organs during metamorphosis. The small, sideways-directed eyes of the tadpole grow into large, bulging eyes that let many frogs have a 360-degree field of vision and the ability to focus both eyes on one object. They gain the ability to move their eyes through the development of large external eye muscles. Eyelids allow frogs to open and close their eyes, which are kept moist by the newly developed tear glands and ducts. The eyes do not only grow but their inner structure and physiology changes. For example, the spherical tadpole lens flattens, the double cornea fuses into a single cornea, and in the light-sensitive retina rhodopsin becomes the dominant photopigment, as it is in most terrestrial vertebrates (and also marine fish).

Both male and female frogs can produce sounds and have a larynx with vocal chords that is not present in the silent tadpoles. Males are the dominant vocalizers in frogs—they are the ones we hear croaking loudly during the spring mating season—and they have, in contrast to females, a vocal sac. It is an outpocketing of the floor of the mouth that fills with air and serves as a resonating body when the male frog produces its sounds.

Anyone who hears a chorus of frogs during the mating season can realize that frogs must have an acute sense of hearing. An eardrum develops that is flush with the outer skin and a middle ear that connects via a bony stirrup (stapes or columnella) with the inner ear, which is the only part of the ear that is developed in tadpoles. For a short time during this reconfiguration of the auditory organs the nascent frog is unable to hear sounds.

Manifold changes occur in other organs such as the brain, kidneys, liver, and pancreas. They are associated with the frog's different mode of perception, circulation, feeding, digestion, and movement. Therefore, as you can imagine by now, these organs also reconfigure both anatomically and physiologically.

The body of a tadpole is very flexible and most of its skeleton consists of cartilage and not bone. As the frog develops, the bone formation increases. The limbs are fully developed after metamorphosis and the muscular hind limbs allow the frog at first to swim well with forceful, rapid thrusts through the water, and then to lead a leaping life on land.

Most frogs leave the aquatic environment and become land dwellers, although they thrive best in moist areas and often stay close to bodies of water. They return to water during the mating season. In the case of wood frogs (*Rana sylvatica*), for example, a female can lay over a thousand eggs, which are externally fertilized by sperm from the males. After fertilization the embryo begins to develop and forms into a tadpole that "hatches" out of its protective gelatinous ball and begins to live its tadpole life.

Thinking Development

In what follows I will be struggling with language. How can I adequately express what reveals itself during a study of amphibian metamorphosis? I don't want to fall back on standard phrasing that takes us away from the concrete richness and dynamism of what is showing itself. I want to stay close to the phenomena, not as a mere collection of facts, but as transformative process. So bear with me. Try to catch my meaning. I'm trying to articulate something about development that usually gets overlooked.

In the process of metamorphosis a way of being we call "tadpole" disappears while a way of being we call "frog" emerges. No investigation of the tadpole alone could ever lead us to the knowledge that it will develop into a frog. The frog does not, in this sense, come from the tadpole. During metamorphosis an organic activity is at work that brings the tadpole to disappear while it brings the frog into appearance. We are witnessing a creative transformative activity as the frog becomes flesh—literally incarnates—during metamorphosis.

What I want to emphasize here is that we are dealing with creative activity and not simply the unrolling of some genetic or developmental "program." Development is not something automatic that just happens. What you find when you closely follow a developmental process is ongoing activity that cannot be accounted for by looking to what came before. You can't find the frog in the tadpole. This is self-evident as long as you attend to the actual process in its own terms.

But since we have been taught that science elaborates the causes of things—and causes, so we imagine, always lie in the past—then evidently the cause of the development of the frog must lie in the tadpole. Scientists start to investigate what substances—such as thyroid hormones—play a role in triggering the onset of metamorphosis, and what genes are turned on and turned off while the tadpole is transforming. This is all interesting, but it is actually just a further elaboration of the process itself at a molecular level. When scientists discover new molecular processes that in turn influence other processes, they are uncovering fascinating details about how the frog is coming into being. They are not "explaining" it.

At the molecular level, processes and substances in very different kinds of organisms are remarkably similar. Many different organisms produce thyroid hormones and, clearly, a boost in their production doesn't turn them into frogs! Researchers may say that thyroid hormone "controls" metamorphic changes in the tadpole-becoming-frog, evidently believing that discovering a substance that may influence the realization of certain events is the same thing as understanding those events. But you don't understand maturation of the skeletal system in human beings or the transformations in the tadpole-becoming-frog by studying only the associated substance-based conditions (hormones or genes); you have to study the human being and the frog. In other words, the activity of hormones or genes can only be understood in the context of the given organism and the specific developmental process. The significance or meaning of the molecular events becomes clear when we understand how they are part of the actual manifestation of the frog, which we need to study in its fullness.

I'm wanting to counter the strong habit of thought that imagines the answer to developmental questions—the key that opens insights into the mystery of development—as lying in the past and in substances, i.e. in what one imagines as physical causes. No matter at what level we consider an organism and its development, we are always dealing with organizing activity or agency that is specific and that provides the context for any part-processes, such as molecular events, that are discovered.

This is not to deny the contribution of the past to a developmental process. I just want to try to think the relation in an adequate, close-to-the-phenomena way. The tadpole of a wood frog develops into a wood frog; the tadpole of a bull frog develops into a bull frog. That is the specificity that inheres in every aspect of a developmental process. In this sense what "is" constrains what can become. But every "is" is in essence activity. This is easy to see in the ongoing creative transformation from fertilized egg (zygote) into embryo into tadpole into frog.

Take T. H. Huxley's beautiful description of a developing embryo, written in 1860 (Huxley was a colleague of Charles Darwin and one of the main early proponents of Darwin's theory of evolution):

> The student of Nature wonders the more and is astonished the less, the more conversant he becomes with her operations; but of all the perennial miracles she offers to his inspection, perhaps the most worthy of admiration is the development of a plant or of an animal from its embryo. Examine the recently laid egg of some common animal, such as a salamander or newt. It is a minute spheroid in which the best microscope will reveal nothing but a structureless sac, enclosing a glairy fluid, holding granules in suspension. But strange possibilities lie dormant in that semi-fluid globule. Let a moderate supply of warmth reach its watery cradle, and the plastic matter undergoes changes so rapid, yet so steady and purpose-like in their succession, that one can only compare them to those operated by a skilled modeller upon a formless lump of clay. As with an invisible trowel, the mass is divided and subdivided into smaller and smaller portions, until it is reduced to an aggregation of granules not too large to build withal the finest fabrics of the nascent organism. And, then, it is as if a delicate finger traced out the line to be occupied by the spinal column, and moulded the contour of the body; pinching up the head at one end, the tail at the other, and fashioning flank and limb into due salamandrine proportions, in so artistic a way, that, after watching the process hour by hour, one is almost involuntarily possessed by the notion, that some more subtle aid to vision than an achromatic, would show the hidden artist, with his plan before him, striving with skilful manipulation to perfect his work. (Huxley 1860)

It's interesting, and I believe significant, that Huxley is moved by the phenomena themselves to reach for the metaphor of the "hidden artist" sculpting the organism. Something creative—something I have referred to as "activity" or agency—is molding the developmental process. But it is not an artist creating something externally. It is the developing organism as artist creating itself. This gives richer meaning to the term "autopoiesis" ("self-creation"), which is often used to characterize the self-organizing capacity of living beings.

There's no need for dualism here. We don't need to think of some being or life force that is somehow outside the process working in. We just need to thoughtfully follow the process itself, and we see everywhere in organic life "being-at-work"—Joe Sach's felicitous translation of Artistotle's term *energeia* (Sachs 2005).

Once we realize the activity-nature of a *developing* organism, we can see that the *mature* organism is also being-at-work. An adult frog carries out numerous activities—leaping with its long and powerful rear legs, catching a fly with its tongue, migrating to a vernal pool to mate, croaking at dusk. In all of these and many more activities we can point to a body and say "that is a wood frog." In all the changing activity there is a certain stability of form (shape, size, color pattern, etc.). While we can identify specific structures, the frog is always actively maintaining these and continually building up, breaking down, and transforming its bodily substances, all in relation to its needs and what it encounters in its surroundings. The frog never "is" in a static sense. It is continually producing and maintaining itself. Its body is the momentary result of ongoing creative activity.

To sum up: I'm encouraging a significant shift in attention. We habitually tend to consider an organism as "that which has become"—the organism as product that consists of a body, of heart and brain, of hormones and genes. We look at how these products are related and organized spatially and how they interact as products (this hormone affecting that organ). We conceive of everything as spatially bounded; we are tied to thingness in our minds, and the organism and its development appear in this light. Processes become the interactions of already existing substances, and development becomes the "chain reaction" sum of those interactions, the cascade of causal events. Time itself becomes "one thing after the other"—a sequence of events—and so also is atomized and made spatial.

Once we become aware of this grip of spatiality and "thingness" on our thinking, we can begin to loosen it when we attend to a developmental process. We attend to the process *as process,* follow closely the ongoing transformation, the coming-into-being and disappearing. We are no longer describing things, but flux and fluid movement. Huxley entered into this kind of attentiveness when observing the embryo, and he felt the need to characterize development as an artistic process. Development now shows itself as a true coming-into-being, the creative activity of life itself. Continuity lies no longer in the inertia of thingness but in the ongoing activity of life unfolding. This activity reveals itself as we move with the process in our thinking. As we observe, the continual flow in thinking is the means through which life-as-activity shows itself. In this mode of attentiveness, we no longer experience time as if from the outside, as a sequence of events, but rather as an ever-new-now, as ongoing creative activity.

This understanding of the organism and individual development (ontogeny) as creative activity opens up new territory and asks us to re-think all our notions that were based on a thing-centered, spatial way of viewing life processes. A biology of no-things—of activities—leads us into a science that takes seriously and strives to do justice to active, interpenetrating beings. And when we turn in this way of knowing to evolution (phylogeny)—the idea that organisms develop into different types of organisms over long periods of time—we realize the limitations of conventional ideas that try to derive what has become out of what was present at earlier times. New challenges to our conceptualization of evolutionary processes emerge and new questions arise. How do we need to think about evolution once we begin to take organisms as beings-at-work seriously?

These are topics I will address in the future. And I'm grateful to frogs for helping me along the way.

Adult bull frog. (Photo: Bill Buchanan/USFWS)

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